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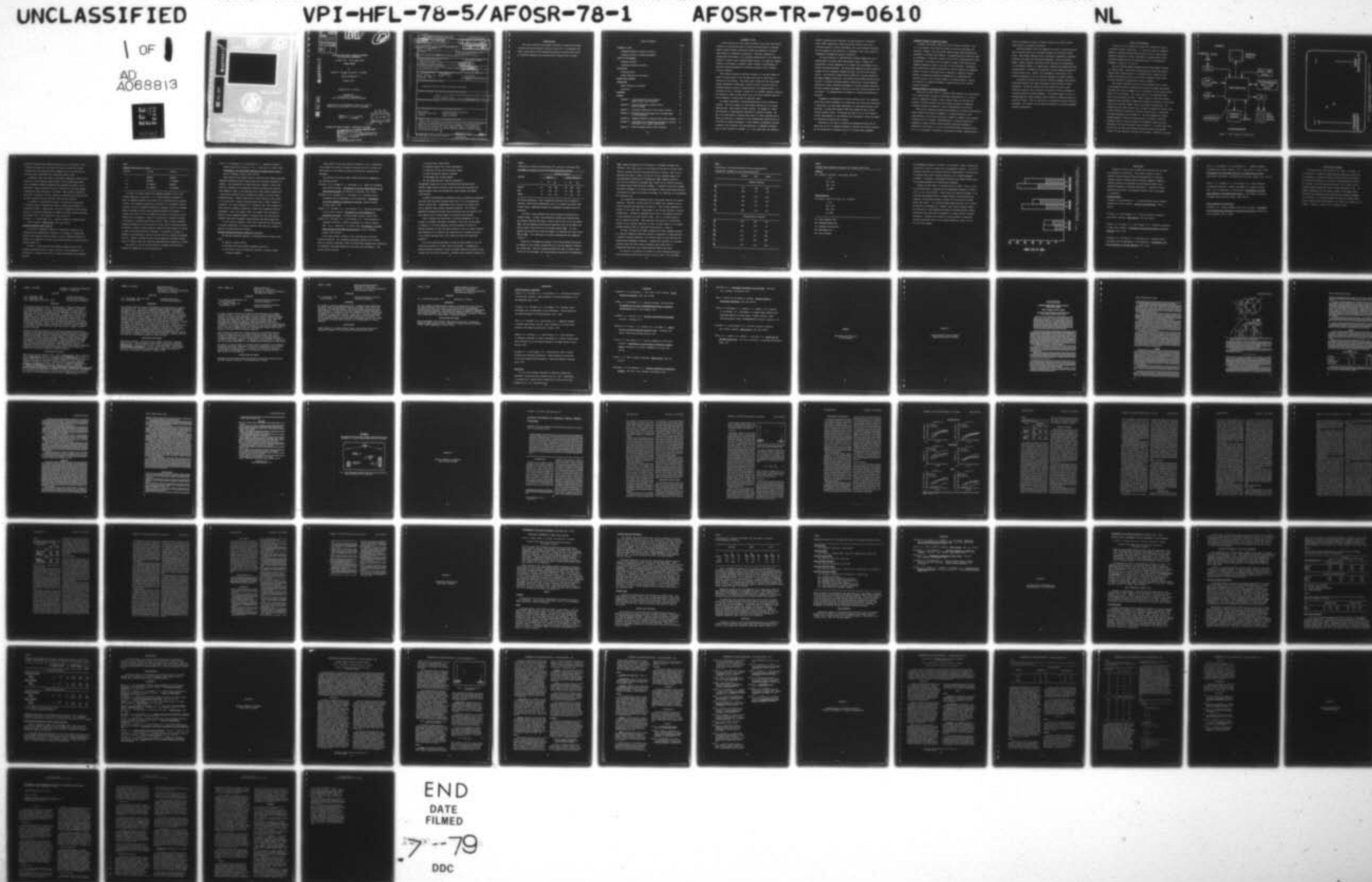

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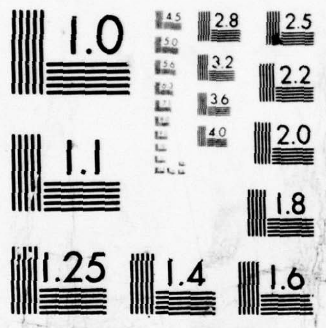

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AUTOMATED MOTOR SKILLS TRAINING OPTIMIZED FOR INDIVIDUAL DIFFERENCES

1 October 1977 - 30 September 1978

ANNUAL REPORT

by

Beverly H. Williges and Robert C. Williges

HFL-78-5/AFOSR-78-1

November 1978

AFOSR Grant No. 77-3161-A

Prepared for
Life Sciences Directorate
Air Force Office of Scientific Research

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

19 REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: 18 AFOSR-TR- 79-0610	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER: 9 Annual rept.	
4. TITLE (and Subtitle): 6 AUTOMATED MOTOR SKILLS TRAINING OPTIMIZED FOR INDIVIDUAL DIFFERENCES	5. TYPE OF REPORT & PERIOD COVERED: [redacted] 1 Oct [redacted]77 - 30 Sep [redacted]78
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): 10 Beverly H. Williges [redacted] Robert C. Williges	8. CONTRACT OR GRANT NUMBER(s): 15 AFOSR-77-3161
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Human Factors Laboratory, Virginia Polytechnic Institute & State University, Blacksburg, Virginia 24061	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 61102F 16 2313A2
11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Office of Scientific Research (NL), Bolling AFB, DC 20332	12. REPORT DATE: 11 Nov[redacted]978
	13. NUMBER OF PAGES: 80
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 12 86p. 17 A2	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

14 VPI-HFL-78-5/AFOSR-78-1

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

motor skills	computer-assisted instruction
individual differences	adaptive training
feedback	pursuit tracking

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes the second year of a research project investigating approaches to individualized motor skills training. Both macro- and micro-models of individualized instruction are researched. Five studies are summarized, two dealing with visual augmented feedback in adaptive motor skills training and three evaluating regression models to predict optimal training group assignment.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

ACKNOWLEDGMENT

This report describes the research performed at Virginia Polytechnic Institute and State University during 1 October 1977 - 30 September 1978 under a grant from the Life Sciences Directorate of the Air Force Office of Scientific Research which was monitored by Captain Jack A. Thorpe.

TABLE OF CONTENTS

STATEMENT OF WORK

A major difficulty in motor skills training is the large inter-subject variability resulting when only one fixed training procedure is employed. However, modern computer technology provides the capability to process large amounts of continually varying data. Therefore, adapting the instructional environment to the learning characteristics of the individual student is a major focus of computer-based training. By using the computer inherent in the design of synthetic flight trainers, the development of effective training programs for individual students in pilot training should be possible.

Motor skills training in synthetic trainers is a critical element of flight training because of the new tasks pilots may be called upon to perform in future warfare. Such tasks might include low-level fast bomber weapons presentation, high-speed, accurate firing of air-to-air and air-to-ground missiles, evasion of enemy missiles, and formation flying. By optimizing the use of synthetic trainers for the original learning, retention, and transfer of these critical motor skills, Air Force personnel should be better equipped to perform these all-important tasks.

Two general approaches to individualizing motor skills training are possible. The first assumes that each student follows his or her unique learning model (micro-model) through training. One example of a micro-model approach to individualized instruction is adaptive training. The use of the term adaptive training often refers to a motor learning task in which the difficulty or complexity of the training task varies directly as a function of student performance. If the student's performance is within a specific error tolerance, the task difficulty or complexity increases until an exit criterion is reached. If, on the other hand, the trainee is

outside a specified error tolerance, the task difficulty is decreased. Kelley (1969) summarized an adaptive training system as requiring a continuous measure of trainee performance, one or more adaptive variables that can change the task difficulty or complexity, and a logic system for automatically changing the adaptive variable(s).

The second approach to individualizing training assumes that only a limited number of learner types (macro-models) exist. Students are categorized on various dimensions as to learner type and assigned to the optimal training alternative. The macro-model approach has been explored by Cronbach and his colleagues (Cronbach and Snow, 1977) with only limited success. The difficulty arises from the inability to uncover appropriate aptitude-treatment interactions. An alternative macro-model approach avoids the need to establish aptitude-treatment interactions by using regression equations to predict individual performance in various training situations. The best predicted performance indicates the optimal training condition for the student. No categorizations of students or training alternatives are necessary.

Fundamental investigations of critical variables need to be completed before more precise statements can be made about the utility and limitations of using micro- and macro-model approaches for individualizing motor learning tasks. Williges and Williges (1978) have summarized some of these critical research issues. To minimize the overall cost of this research, initial investigations in the laboratory were performed to reduce the number of alternatives requiring field testing.

Specifically, two areas of research were emphasized during 1977-78. These were the role of augmented feedback in adaptive motor skills training and the usefulness of regression models for training group assignment.

Augmented Feedback in Adaptive Training

Bilodeau and Bilodeau (1961) state that "studies of feedback...show it to be strongest, most important variable controlling performance and learning." However, the Kelley (1969) adaptive logic system minimizes the usefulness of intrinsic task feedback. By manipulating task difficulty based on performance, a relatively constant level of error is maintained over time. Consequently, the student sees no progress in terms of error and may need augmented feedback in terms of the level of task difficulty. Although he never evaluated his position experimentally, Kelley contends that augmented feedback in terms of task difficulty is essential in adaptive training. However, providing task difficulty feedback may be a complicated and expensive aspect of the training program in an applied setting. Clearly, the necessity for augmented feedback in adaptive motor skills training required evaluation.

Regression Models in Training Assignment

Recent work by Pask (1976) on cognitive tasks indicates that the matching of the instructional strategy and individual characteristics is a critical factor in maximizing training. Pask's research points out that when the student's preferred learning style and teaching strategy are mismatched, learning is severely disrupted in terms of comprehension and retention.

Historically, matching instructional strategies with learner characteristics either involved the subjective judgment of a skilled instructor or the quantification of the factors that cause a student to respond to one training technique and not to another. Methodologically, the latter requires the comparison of payoff functions from alternative training strategies to determine if they differ, i.e., does an aptitude-treatment interaction exist. If so, it is necessary to determine a classification scheme, including cutoff

scores on pretests, in order to classify students into various learner types related to training alternatives.

Conway and Norman (1974) have suggested five types of information which may be relevant factors for classifying students into different learner types. They include cognitive styles, personality, experience, psychomotor abilities, and social and educational background. Vreuls, Wooldridge, Conway, Johnson, Freshour, and Norman (1977) reported on the development of a preliminary version of a higher-order, partially self-organizing flight training system. Eventually the system was to have included provisions for various learner types. However, the development of this aspect of the system was delayed by a lack of data and techniques to classify students.

A proposed alternative for objective training assignment uses multiple regression equations that model performance in each available training alternative. The pretest results from each student are used in each prediction equation, and the equation predicting the "best" performance in training determines training assignment. This approach makes no effort to determine <u>why</u> the various equations predict different training outcomes for a specific student. They are used solely to determine the optimal training assignment. The validity of this proposed technique for training assignment required investigation.

STATUS OF THE RESEARCH

During 1977-78, five empirical studies were conducted to fulfill two general research requirements: (1) explore the need for augmented feedback in adaptive training (Study I and II) and (2) cross-validate regression equations to predict performance in training under various training strategies and use the predicted scores for training group assignment. (Study III, IV, and V).

The five research studies completed used the same general training and transfer tasks. These tasks were generated by a PDP 11/10 digital computer which provided inputs to a Tektronix 4014-1 cathode ray tube display and processed control outputs from an isometric control stick. The data acquisition configuration is shown in Figure 1.

Each subject completed a series of 3-min tracking trials to learn a two-dimensional pursuit tracking task in which two random, band-limited functions were used to determine the x-y coordinates of the forcing function symbol "X" on the display. The control output "O" was generated using inputs from the analog controller. Figure 2 shows the task where dynamic, augmented visual performance feedback was presented in addition to the forcing function and controller symbols used in the pursuit tracking task. One feedback bar (the right vertical line in Figure 2) depicted the current level of task difficulty in relation to the exit criterion level of difficulty (the right horizontal line on Figure 2). The left feedback bar showed a smoothed measure of current tracking accuracy in relation to both the acceptable level of accuracy required by the adaptive logic and perfect performance (the left two parallel lines on Figure 2). In other words, when the vertical line depicting tracking accuracy was within the tolerance allowed, the task difficulty vertical line increased. Conversely, the task

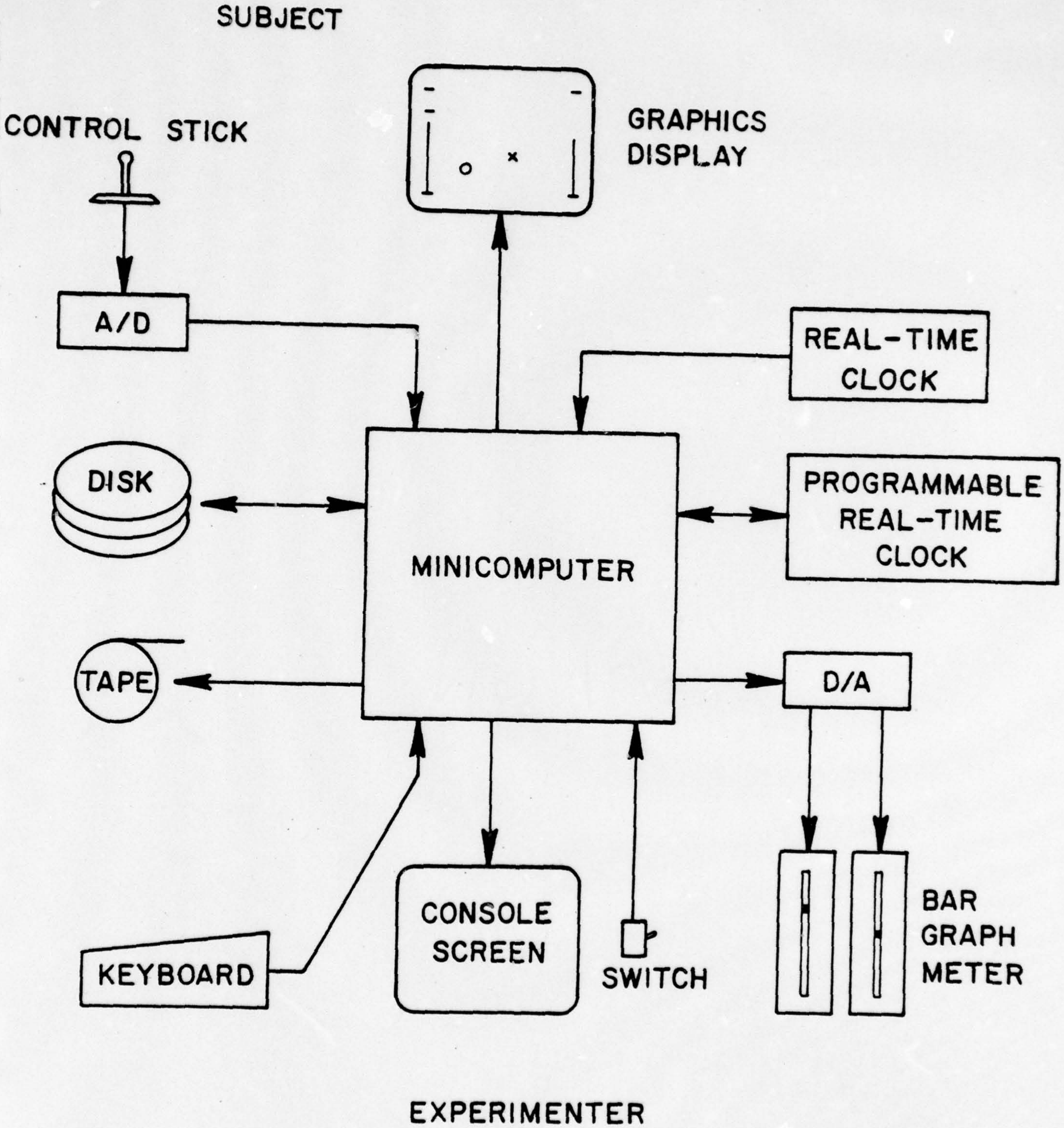

Figure 1. Data acquisition configuration

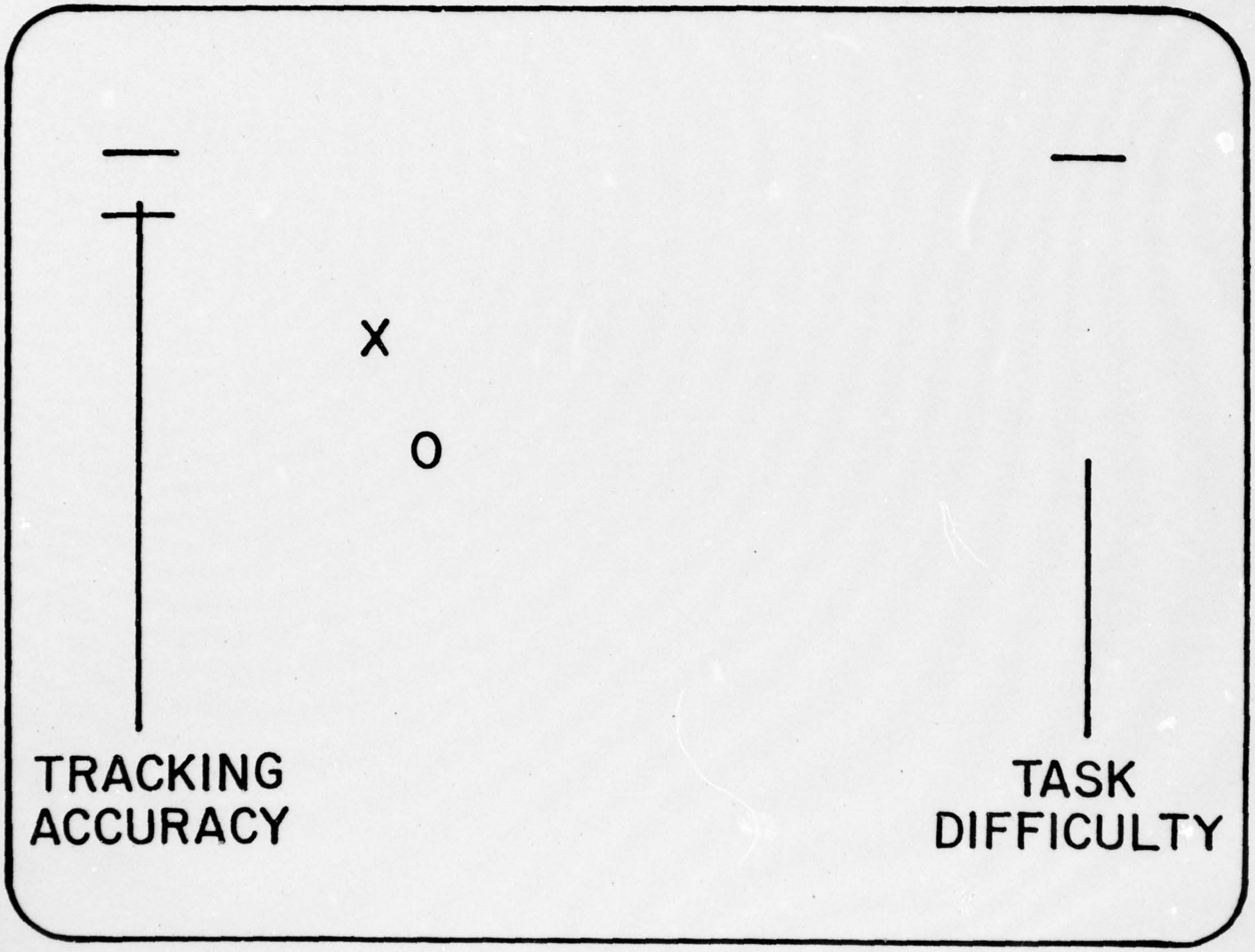

Figure 2. Two-dimensional pursuit tracking task with adaptive logic and augmented feedback indicators.

difficulty decreased when tracking accuracy was out of tolerance. This procedure continued until the subject was able to perform the pursuit tracking task while maintaining both feedback bars at or above the exit criterion lines continuously for a specified period of time.

Following a short rest period, each subject completed a transfer task which was a 7-min tracking session similar to the training task except that no augmented feedback information was provided (see Study I for an exception). During transfer the level of difficulty of the task changed automatically after each minute of tracking. Three levels of difficulty were used: the same as the exit criterion in training, more difficult than the exit criterion, and less difficult than the exit criterion.

In addition to the empirical studies, a review article pertaining to research issues in adaptive motor skills training was published in a professional journal. Specifically, this article summarizes various issues related to performance measurement in adaptive training, adaptive variables, and adaptive logic. The reference for this article is:

Williges, R. C. and Williges, B. H. Critical variables in adaptive motor skills training. Human Factors, 1978, 20, 201-213.

Augmented Feedback (Study I and II)

In the area of augmented feedback two studies were conducted, one comparing various combinations of feedback - no feedback in training and transfer using adaptive training (Study I) and one comparing conditions of feedback or no feedback in training using either adaptive or fixed-difficulty training (Study II).

In Study I 24 male subjects were randomly assigned to one of four treatment combinations given in Table 1 and were trained adaptively. No differences in training time-to-exit or transfer performance were exhibited ($p > 0.10$).

TABLE 1

Treatment Combinations in Study I

Condition	Training	Transfer
I	Feedback	Feedback
II	Feedback	No Feedback
III	No Feedback	Feedback
IV	No Feedback	No Feedback

In Study II 24 male subjects were randomly assigned to one of four training conditions. These were: (1) a fixed-difficulty procedure in which no augmented feedback was presented, (2) a fixed-difficulty procedure in which visual augmented feedback was presented, (3) an automatic adaptive procedure in which no augmented feedback was presented, and (4) an automatic adaptive procedure in which visual augmented feedback was presented. A transfer task similar to the training task was given to all groups in which feedback was not presented. Results of the analysis of variance indicated no difference in training time-to-exit ($p>0.10$). Thus, visually presented augmented feedback did not aid subjects in either type of training procedure. Furthermore, subjects trained adaptively required the same amount of training as those in the fixed-difficulty conditions. The presence or absence of feedback in training did not prove to have any effect on transfer performance ($p>0.10$). However, subjects who were trained adaptively performed reliably better in transfer than those receiving fixed-difficulty training ($p = 0.0065$).

The results of the two initial studies on augmented task difficulty feedback are summarized in the following report.

Cote, D. O., Williges, B. H., and Williges, R. C. Augmented feedback in adaptive motor skill training. In E. J. Baise and J. M. Miller (Eds.) Proceedings of the 22nd annual meeting of the Human Factors Society, Detroit, Michigan, October, 1978, 105-109.

These results do not support Kelley's contention that visually presented augmented feedback decreases training time and/or improves performance in transfer. Two explanations for these results are possible. Either task difficulty feedback is not essential in adaptive training when intrinsic task feedback is high, or the training task in these studies imposed such a large visual workload that the students were unable to use the visual feedback provided. Indeed a high level of visual workload is most likely to be encountered in complex training systems such as flight training in simulators. For these situations it is imperative that other channels for task difficulty feedback be explored if indeed this information improves performance. Gilson and Ventola (1976), for example, have successfully employed tactile augmented feedback to present pilots with task-specific feedback flight path information during approach and landing operations.

A study currently underway at VPI & SU is exploring the effectiveness of various combinations of visual and auditory task difficulty feedback in adaptive and fixed-difficulty training.

Training Alternative Selection (Study III, IV, and V)

The multiple regression approach to training selection involves three steps:

(1) Develop a pretest battery

(2) Determine and cross-validate regression equations

(3) Use pretest scores and regression equations to predict optimal training assignment

Three studies in this area have been completed -- two to develop and cross-validate the multiple regression equations and one to evaluate the effectiveness of the regression equation procedure for training group assignment.

The results of the three studies completed have been summarized in the following reports:

Williges, B. H., Williges, R. C., and Savage, R. E. Models for automated motor skills training. Proceedings of the 21st annual meeting of the Human Factors Society, San Francisco, California, 1977, 18-22.

Williges, B. H., Williges, R. C., and Savage, R. E. Matching initial performance and the measurement of sex differences. Proceedings of the 6th symposium on Psychology in the DoD, Colorado Springs, Colorado, April, 1978.

Savage, R. E., Williges, R. C., and Williges, B. H. Individual differences in motor skill training. Proceedings of the 6th symposium on Psychology in the DoD. Colorado Springs, Colorado, April, 1978.

Savage, R. E., Williges, R. C., and Williges, B. H. Cross-validation of regression equations to predict performance in a pursuit tracking task. In E. J. Baise and J. M. Miller (Eds.) Proceedings of the 22nd annual meeting of the Human Factors Society, Detroit, Michigan, October, 1978, 369-372.

In all three studies a battery of six tests was used to provide predictor variables. The information processing variables were included based on the work by Martenuik (1976) and others which suggests that limitations in information processing capabilities can limit motor performance. The pretest battery included:

(1) Pursuit Rotor (motor skill)

(2) Embedded Figures Test (field independence)

(3) Identical Pictures Test (perceptual speed)

(4) Maze Tracing Test (spatial scanning)

(5) Map Memory Test (visual memory)

(6) Cube Comparison Test (spatial orientation)

The Embedded Figures Test is from the Educational Testing Service (Witkin, Oltman, Raskin, and Karp, 1971), and the last four tests are paper-and-pencil tests from the Ekstrom, French, Harman, and Derman, (1976) battery.

A double cross-validation procedure was used to validate the regression equations which predicted training time-to-exit in the two-dimensional pursuit tracking task. Standardized scores from the six pretests were used to generate least squares regression equations. Five stepwise regression procedures were used, and the equations that accounted for the most variance with the least number of predictors were selected.

Table 2 presents the coefficient of multiple determation, R^2, the estimate of shrinkage (Kerlinger and Pedhazur, 1973), R_s^2, and the number of subjects, n, for each regression equation generated in Study III. Separate equations for male and female subjects as well as overall equations were generated for the adaptive and fixed-difficulty training conditions. In the overall equations sex of the student was used as an additional predictor.

All of the equations generated in Study III were reliable at the .05 level and accounted for at least 43% of the variance. In general the separate equations generated for male and female subjects accounted for more variance than the overall equations. Although sex was used as a predictor in

TABLE 2

Coefficients of Multiple Determination (R^2), Estimate of Shrinkage (R_s^2), and Number of Subjects (n) for First-Order Regression Equations

Subjects	Training Condition					
	Adaptive			Fixed Difficulty		
	n	R^2	R_s^2	n	R^2	R_s^2
Overall	31	.721	.690	28	.639	.610
Male	17	.750	.717	16	.803	.758
Female	14	.817	.756	12	.431	.374

the overall equations, it was a significant predictor only for adaptive training. These results demonstrated that it is possible to predict time-to-exit using a regression approach and information processing factors as predictors.

In Study IV cross-validation data were obtained by replicating the original design. A double cross-validation procedure was employed where the original equations were used to predict time-to-exit for the new sample ($R^2_{\hat{1}2}$), and new regression equations were generated from the new sample and used to predict time-to-exit for the original sample ($R^2_{\hat{2}1}$). For both samples correlations were calculated between the predicted and actual scores ($R^2_{\hat{1}1}$ and $R^2_{\hat{2}2}$). The coefficients of multiple determination are summarized in Table 3.

Reduction or shrinkage was expected in the cross-validated correlation as compared to the original correlations due to the new samples of subjects and testing time. When the original equations were used to predict time-to-exit for the new sample, the cross-validated coefficient of determination

(R^2_{12}) compared favorably with the estimates of shrinkage (Kerlinger and Pedhauzer, 1973) ($R^2_{s_1}$) except for the equations developed for females using adaptive training and males using fixed-difficulty training. When the new equations were used to predict time-to-exit for the original samples, the cross-validated coefficients of determination (R^2_{21}) compared relatively well with the estimates of shrinkage ($R^2_{s_2}$) except for the equation developed for females using fixed-difficulty training. It should be noted that although the actual shrinkage of the equation developed for males using fixed-difficulty training did not exceed the estimated shrinkage, the coefficient of determination was relatively low.

The coefficients of determination were consistently high for the overall equations. Therefore, the data from the two samples were combined, and new overall equations were generated (see Table 4). Each of these equations is reliable at the .0001 level. These appear to be the best equations to predict training time. Although the Embedded Figures Test is the dominant predictor in both equations, all other factors differ. Sex is a reliable predictor only for adaptive training. These equations were selected to discriminate between the two training conditions in order to assign students to an optimal training condition based on individual characteristics (Study V).

In Study V 60 male and 60 female students were either randomly assigned or, using the regression equations, matched or mismatched to fixed-difficulty or adaptive training conditions. The critical aspect of this study was the training group assignment techniques. Students were "matched" to a training condition based upon their shorter predicted time-to-exit score or "mismatched" based upon their longer predicted time-to-exit score.

The results of an analysis of variance on actual training time-to-exit scores indicated reliable main effects of sex, $\underline{F}$ (1,108) = 40.6, $\underline{p}$<0.0001,

TABLE 3

Coefficients of Multiple Determination from Cross-Validation

(Original R^2, Shrunken R^2, and Cross-Validation R^2)

	Overall	Male	Female
	Adaptive Training		
$\hat{R}^2_{11}$	.721	.750	.817
$R^2_{s_1}$	.690	.717	.756
$\hat{R}^2_{12}$	.832	.619	.306
$\hat{R}^2_{22}$	.859	.841	.827
$R^2_{s_2}$	.833	.796	.741
$\hat{R}^2_{21}$	.699	.578	.511
	Fixed-Difficulty Training		
$\hat{R}^2_{11}$	.639	.803	.431
$R^2_{s_1}$	.610	.758	.374
$\hat{R}^2_{12}$	.444	.178	.482
$\hat{R}^2_{22}$	.611	.474	.905
$R^2_{s_2}$	.538	.324	.856
$\hat{R}^2_{21}$	.472	.333	.003

TABLE 4

Combined Sample Regression Equations for Training Time-to-Exit

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<u>Adaptive</u>

$$TE = 1326.85 + 381.82\ EF - 307.48\ MM + 259.52\ SE$$

$n = 51$

$R^2 = .756$

$R_s^2 = .740$

$p \leq .0001$

<u>Fixed Difficulty</u>

$$TE = 994.57 + 405.77\ EF + 251.3\ IP - 139.28\ CC$$

$n = 48$

$R^2 = .632$

$R_s^2 = .607$

$p \leq .0001$

CC = Cube Comparison Test

EF = Embedded Figures Test

IP = Identical Pictures Test

MM = Map Memory Test

SE = Sex of Student

and assignment procedure, F (2,108) = 17.27 $p<0.0001$. Figure 3 depicts the time-to-exit scores by training type and assignment procedure. Use of the regression equations for training resulted in approximately a 50% reduction in training time in both training conditions over a random assignment procedure. In addition, within-group variability was reduced 30-60% using the matching procedure for training group assignment.

Neither the main effect of training type, F (1,108) = 1.36, p = 0.25, nor the interaction of training type and assignment procedure, F (2,108) = 1.01, p = 0.37, were reliable. These results are important because, if the study had been designed merely to compare adaptive and fixed-difficulty training, it would have provided no support for selecting one training method over another. The training designer might then feel free to choose arbitrarily one training type. However, these results strongly support the efficiency of individualizing training by providing several training alternatives and using multiple regression to predict the best training performance. Currently this research is being extended to additional training alternatives and to a new student population, cadets from the U.S. Air Force Academy.

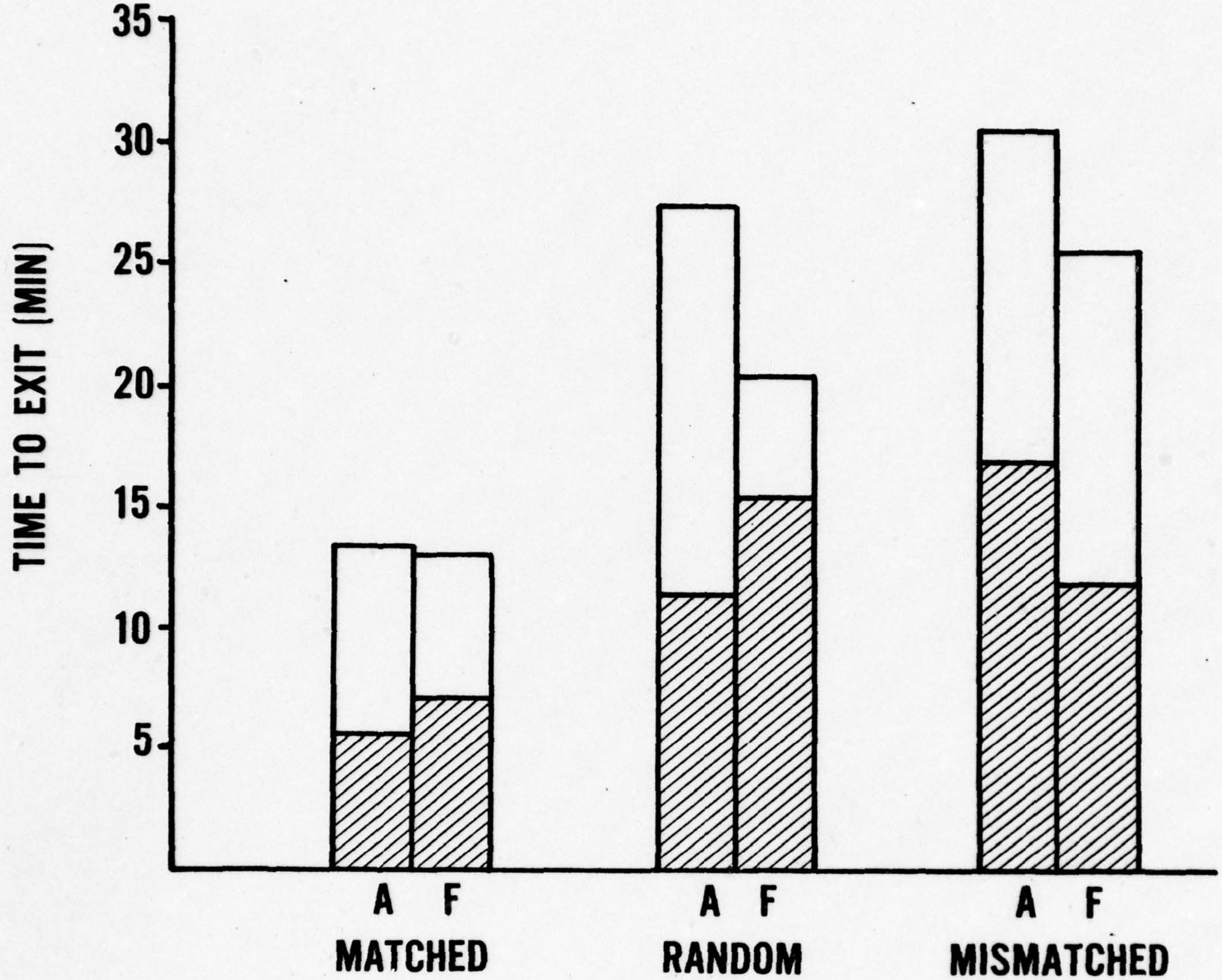

Figure 3. Average training time-to-exit scores by assignment procedure and training type (females-solid bars; males-cross-hatched bars).

PUBLICATIONS

During the contract year six papers were published, and one paper was submitted for publication. These papers include a review of adaptive training research issues and presentations of laboratory research related to learner-centered training, augmented feedback in adaptive training, sex differences and matching procedures, and a regression approach to individual differences. Citations for these papers are given below. The Appendix includes a copy of each paper or an abstract.

Published Papers

Williges, B. H. and Williges, R. C. Learner-centered versus automatic adaptive motor skill training. Journal of Motor Behavior, 1977, 9, 325-331.

Williges, R. C. and Williges, B. H. Critical variables in adaptive motor skills training. Human Factors, 1978, 20, 201-214.

Savage, R. E., Williges, R. C., and Williges, B. H. Individual differences in motor skill training. Proceedings of the Sixth Psychology in the DoD Symposium, April, 1978.

Williges, B. H., Williges, R. C., and Savage, R. E. Matching initial performance and the measurement of sex differences. Proceedings of the Sixth Psychology in the DoD Symposium, April, 1978.

Cote, D. O., Williges, B. H., and Williges, R. C. Augmented feedback in adaptive motor skill training. In E. J. Baise and J. M. Miller (Eds.) Proceedings of the 22nd Annual Meeting of the Human Factors Society. Santa Monica, California: The Human Factors Society, October, 1978, 105-109.

Savage, R. E., Williges, R. C., and Williges, B. H. Cross-validation of regression equations to predict performance in a pursuit tracking task. In E. J. Baise and J. M. Miller (Eds.) Proceedings of the 22nd Annual Meeting of the Human Factors Society. Santa Monica, California: The Human Factors Society, October, 1978, 369-372.

Papers Submitted for Publication

Williges, B. H. Computer augmented motor skills training. Proceedings of the International Conference on Cybernetics and Society, Tokyo-Kyoto, Japan, November, 1978, in press.

PROFESSIONAL PERSONNEL

The research effort was directed by Dr. Robert C. Williges, who is a professor in industrial engineering and operations research and of psychology at Virginia Polytechnic Institute and State University. Dr. Williges was assisted by a part-time research associate, Beverly H. Williges, a full-time research associate, John E. Evans, and two graduate research assistants, Ricky E. Savage and David O. Cote. Mr. Evans is responsible for all computer support at the Human Factors Laboratory and provided the task simulation and systems programming for the project. Ms. Williges managed the empirical research effort. Messrs. Savage and Cote participated in the conduct and analysis of the research. Resumes of these five key personnel follow.

ROBERT C. WILLIGES | Professor of Industrial Engineering
Professor of Psychology

EDUCATION

A.B., Psychology, 1964 — Wittenberg University
M.A., Psychology, 1966 — The Ohio State University
Ph.D., Engineering Psychology, 1968 — The Ohio State University

EXPERIENCE

Dr. Williges joined the staff of the Department of Industrial Engineering and Operations Research in 1976. Before becoming a member of the faculty at Virginia Polytechnic Institute and State University, he spent eight years from 1968 to 1976 as a member of the Department of Psychology at the University of Illinois at Urbana-Champaign. In addition to his teaching appointment, he was associated both with the Highway Traffic Safety Center (1968-70) where he conducted research on human factors applications to highway systems and the Aviation Research Laboratory (1970-76) where he conducted research dealing with pilot training and enhancement of aircraft controls and displays. While at The Ohio State University he was employed at the Human Performance Center (1964-68) and conducted simulation research on air traffic control systems and human monitoring of complex, computer-generated displays.

Besides his extensive experience in conducting and managing human factors research, he has taught both graduate and undergraduate courses in statistics, research methodology, industrial psychology, human performance, engineering psychology, and human factors in systems design. His publications in human factors include topics dealing with team training, decision making, simple and complex visual monitoring performance, inspection behavior, and human performance in complex system operation including investigation of rate-field, frequency-separated, predictor, computer-generated, and time-compressed displays, interpretability of TV-displayed cartographic information, applications of response surface methodology, motion cues in simulation, transfer of training, and adaptive training procedures.

AFFILIATIONS AND AWARDS

Human Factors Society (Fellow, 1975): editor, Human Factors (1976), associate editor, Human Factors (1973-75), reviewing editor, Human Factors (1971-73), publications board (1974-75), and president, Sangamon Valley Chapter (1971-72); American Psychological Association (Fellow, Division 21, 1975); secretary-treasurer, Division 21 (1972-76); consulting editor Catalog of Selected Documents in Psychology (1975-76); Psi Chi; and occasional reviewing editor for Journal of Experimental Psychology, American Journal of Psychology, Journal of Applied Psychology, and Behavioral Research Methods and Instrumentation. He is listed in the American Men and Women of Science, Who's Who in the Midwest, and 1978 Outstanding Young Men of America, and was awarded the 1974 Jerome H. Ely Award for the outstanding article published in Human Factors during 1973.

BEVERLY H. WILLIGES

Research Associate
Human Factors Laboratory
Department of Industrial Engineering
and Operations Research

EDUCATION

A.B., Psychology, 1965 (cum laude) — Wittenberg University
M.A., Psychology, 1968 — The Ohio State University

EXPERIENCE

Ms. Williges joined the staff of the Human Factors Laboratory as a research associate in 1976. Her primary responsibilities include the development and supervision of research on automated training systems, the design of experiments, statistical analysis, and report preparation. From 1971-1976 she was a research associate at the Aviation Research Laboratory, University of Illinois, where she was involved in basic and applied research to develop adaptive systems for pilot training. Previously, she worked for Battelle Memorial Institute, Columbus Laboratories, where she was responsible for the development of self-instructional training programs to be used in industry, government, and education. She was also involved in the collection, evaluation, and interpretation of large-scale survey data. While at Battelle she attended a short course at the University of Michigan for writers of programmed instruction. Her primary research interests are in the areas of motor learning, computed-augmented instruction, and simulation. Her publications include self-instructional training programs and papers dealing with research on simulation, learner-centered instruction, computer adaptive training, and individual differences in motor learning.

AFFILIATIONS AND AWARDS

Human Factors Society: Executive Council, member (1976-1981); Training Technical Group, steering committee (1975-1978), chairperson (1978-1979); Human Factors: associate editor (1975); consulting editor (1976-present); Aviation Research Monographs: associate editor (1971-1973); Alpha Lambda Delta: Psi Chi; Delta Phi Alpha; Mortar Board; Charles Platt Award in Psychology; Outstanding Young Woman of America (1978).

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EXPERIENCE

Mr. Evans joined the staff of the Human Factors Laboratory as a research associate in 1976. He has since been involved in systems software modifications, corrections, and enhancements and applications software development including real-time simulation, dynamic computer graphics, data reduction, real-time data acquisition, computer transaction systems design and implementation, program debugging aids and instrumentation and on-line experiment control using intercommented DEC PDP 11/10 and 11/55 mini-computers. In addition, he has been involved in systems and applications software development in the area of magnetic tape file processing and program library maintenance on the IBM 370/158 university computers.

From 1975-1976 Mr. Evans was a systems analyst in the Technical Computer Systems Development Group at the Shell Information Center, Shell Oil Co. in Houston, Texas where he was involved in systems software development, program instrumentation, and systems measurement and performance evaluation for UNIVAC 1100 series computers. In addition, he was involved in utility and user aid software development for the VM/CMS system operating on an IBM 370/158.

Previously, Mr. Evans worked as a graduate research assistant in the Computer Engineering Laboratory, Department of Electrical Engineering, VPI & SU where he developed a software system . In addition, he developed an extensive Fortran callable subprogram library providing many processing extensions to ANSI Fortran IV on the IBM 360.

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EXPERIENCE

Mr. Savage is currently completing his M.S. in human factors engineering. He has two years of undergraduate research experience at VPI & SU in the Department of Psychology working in the area of human learning and human choice behavior. He also has two years of graduate research experience at the Human Factors Laboratory at VPI & SU working in the area of individual differences in motor skill training. Other areas of research experience include the measurement of operator workload and visual perception. His primary research interests are individual differences in motor skill training, adaptive training, human learning, and the measurement of operator workload.

AFFILIATIONS

Student member of the Human Factors Society, the American Institute of Industrial Engineers, and the American Psychological Association

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EXPERIENCE

Mr. Cote entered the Human Factors program at Virginia Polytechnic Institute and State University in the Fall of 1977 and has served as a graduate assistant since that time. While pursuing his M.S. in industrial engineering, he has conducted research on the effects of augmented feedback in adaptive motor skills training. His primary research interests are in safety, training, and the application of human factors to military systems.

AFFILIATIONS AND AWARDS

Second Lieutenant, United States Army; American Institute of Industrial Engineers; Human Factors Society: Member of Training and Safety Technical Groups; Student Ambassador to Brazil (1973)

INTERACTIONS

Papers Presented at Meetings

Savage, R. E., Williges, R. C., and Williges, B. H. Individual differences in motor skill training. Paper presented at the Sixth Psychology in the DoD Symposium, April, 1978.

Williges, B. H., Williges, R. C., and Savage, R. E. Matching initial performance and the measurement of sex differences. Paper presented at the Sixth Psychology in the DoD Symposium, April, 1978.

Cote, D. O., Williges, B. H., and Williges, R. C. Augmented feedback in adaptive motor skill training. Paper presented at the 22nd Annual Meeting of the Human Factors Society, October, 1978.

Savage, R. E., Williges, R. C., and Williges, B. H. Cross-validation of regression equations to predict performance in a pursuit tracking task. Paper presented at the 22nd Annual Meeting of the Human Factors Society, October, 1978.

Williges, R. C. and Williges, B. H. Automated motor skills training optimized for individual differences. Paper presented at the Review of Air Force Sponsored Basic Research: Flight and Technical Training, April, 1978.

Consulting

U.S. Air Force Academy, Department of Behavioral Science and Leadership, Colorado Springs, Colorado, April 22, 1978. Coordination of proposed joint research effort between VPI & SU and the Air Force Academy with Lt. Col. Jefferson Koonce.

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APPENDIX

Manuscripts and Abstracts of Publications

Appendix A

Learner-Centered versus Automatic Adaptive Motor Skill Training

Journal of Motor Behavior
1977, Vol. 9 No. 4, 325-331

LEARNER-CENTERED VERSUS AUTOMATIC ADAPTIVE MOTOR SKILL TRAINING

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Three types of training (fixed-difficulty, automatic-adaptive, and learner-centered) were used to teach 18 male and 18 female students a two-dimensional pursuit-tracking task. A 7-min tracking session, in which task difficulty shifted each minute, was used to measure transfer. Although training type did not result in differences in training time, students trained under learner-centered procedures had less tracking error during transfer. Females required on the average twice as much training as males. During transfer no sex differences were noted. The differences in training time for males and females may reflect previous experience with similar motor-control tasks.

Recently a great deal of research has been directed toward individualizing motor skills training. Specifically, automatic adaptive training techniques have been investigated under the assumption that such training provides an optimum learning model for motor skills. The adaptive model assumes that the task is never too easy or too difficult, much like the training provided by a skilled individual instructor (see Kelley, 1969b). Adaptive training is a closed-loop system in which some aspect of the student's performance is monitored and used in a computer algorithm to adjust the difficulty of the training task. As a result of this feedback loop, the level of student performance remains relatively stable over the training period, while task difficulty fluctuates upward and downward. The adaptive training model optimizes training by *individually* adjusting task difficulty for a wide range of skill levels.

The antithesis of this approach puts control of the lesson in the hands of the student. Learner control may take two different forms: decisions about strategy or decisions about content (Merrill, Note 1). Interest in learner-centered instruction has grown out of the need to provide effective and economical instruction for students of different backgrounds and with various learning styles.

Mager and his associates conducted the early research on learner control. Mager and Clark (1963) reviewed this research and concluded that learner-centered instruction resulted in an improved student attitude toward learning and in some cases reduced training time. Campbell (1964) found that the effectiveness of learner-controlled instruction was no different

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Contractual support for this project was provided by the Life Sciences Program, Air Force Office of Scientific Research, Contract Number F44620-70-C-0105 with the University of Illinois at Urbana-Champaign and Grant Number 77-3161 with Virginia Polytechnic Institute and State University. Dr. Alfred R. Fregly was the scientific monitor. The authors wish to thank Roger A. Hunt who provided software support for the research.

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than fixed-sequence instruction unless students were coached in self-direction. With student coaching, learner-centered instruction was superior in terms of final test scores.

More recent research conducted at the Naval Personnel and Training Research Laboratory (Fredericks, Note 2; Lahey, Crawford, & Hurlock, Note 3; Lahey, Hurlock, & McCann, 1973; McCann, Hurlock, & Lahey, Note 4; Slough, Ellis, & Lahey, Note 5) supports the following conclusions: (a) learner-centered instruction provides motivation for students; (b) learner control does not interfere with instruction; and (c) in some cases, learner-centered instruction results in reduced training time.

The effectiveness of learner-centered instruction may differ for various types of students. Fry (1972) studied learner-centered instruction with students divided into high/low aptitude and high/low inquiry groups. In all groups but the low-aptitude/high-inquiry, students preferred the learner-centered approach. However, improved training was achieved with learner-centered instruction only by the high-aptitude/high-inquiry students.

Learner-centered instruction has two primary advantages. First, because elaborate logic schemes for selecting content or sequence are unnecessary, learner-centered instruction is economical to develop. Second, with learner-centered instruction, the students learn to evaluate their own performance and develop their own internal feedback. Adams (1971) contends that developing an internal feedback model is an essential element in motor learning. However, all of the research on learner-controlled instruction has involved cognitive, rather than motor, learning. It is unclear as to how learner control of the instructional sequence in motor learning will affect the learning process.

The present study was conducted to investigate learner control in motor skills training. Specifically, the experiment was carried out to compare the relative effectiveness of three types of training in learning a two-dimensional tracking task. The three types of training were: (a) *fixed-difficulty training* — this is the traditional learning situation in which task difficulty is always at the exit criterion level, and student performance improves as the task is learned; (b) *automatic-adaptive training* — this condition uses a computer algorithm and some aspect of student performance to manipulate task difficulty and maintain a stable level of performance during training; (c) *learner-centered training* — this condition has the student directly controlling increases or decreases in task difficulty during training. Additionally, the relative effectiveness of these training types for males and females was examined. Effectiveness was evaluated using both training and transfer measures.

Method

Experimental task. All of the students learned a two-dimensional pursuit tracking task. Figure 1 illustrates the display presented to the students. Two random, band-limited functions were used to determine the X-Y coordinates of the forcing function symbol ("X" on the display). Operator control input (symbolized by an "O" on the display) was generated using inputs from the isometric controller. The size of the two symbols was restricted to a .55-x-.40-cm rectangle. Effective screen size for the movement of the symbols was 7.6 cm x 7.6 cm. Outside the movement area of the symbols, two performance bars appeared, one on each side of the display. The bar on the right indicated the level of task difficulty, and the bar on the left provided performance feedback in terms of the tracking accuracy of the student. On each performance bar, an exit criterion line appeared about three-fourths of the way up the bar indicating acceptable performance.

Training was divided into 3-min tracking sessions and 1-min rests, and continued until the exit criterion was reached. To obtain the exit criterion, students had to get both performance bars up to or above the exit criterion lines and keep them there for a period of 20 continuous sec.

Task difficulty, in terms of movement of the forcing-function symbol, was manipulated by changing the band-limited, low-pass filter. The criterion level of task difficulty during training was .55 Hz. A small-step adaptive logic was used to manipulate forcing function frequency. Absolute vector tracking error was computed every 60 msec and, in the adaptive condition,

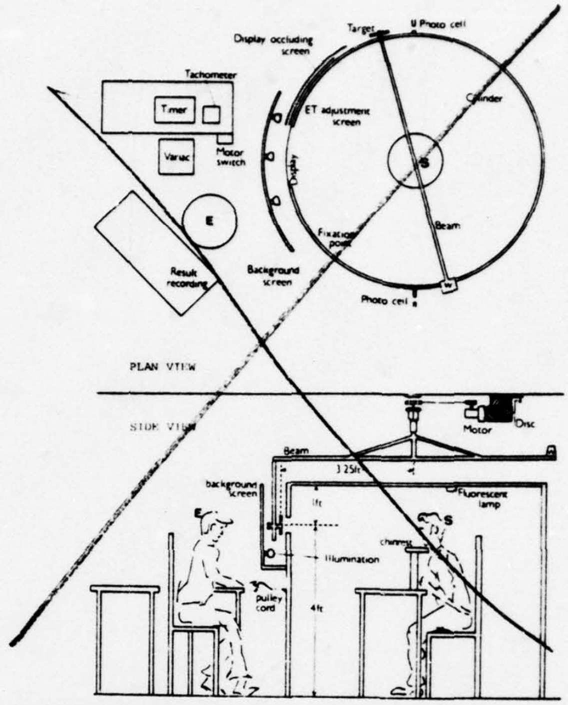

Fig. 1. Pursuit tracking display indicating the forcing function and operator control input symbols, the feedback bars, and the exit criterion lines.

was compared to a tolerance limit of 14% of the screen diagonal. Whenever tracking error was within tolerance, the forcing function frequency was increased by .0005 Hz; whenever tracking error was outside of tolerance, the forcing function was decreased by .0005 Hz. In the learner-centered condition, task difficulty changed upward or downward by .0005 Hz/60 msec whenever the student pressed one of the two buttons on the keyset.

For each control stick output the corresponding positions of the "O" under both pure rate and pure acceleration control dynamics were calculated. The actual new position of the "O" was determined by the formula

$$\Theta_o = (1-\alpha)\ \frac{K}{S} + \alpha\ \frac{K}{S^2}, \tag{1}$$

where Θ_o equals the order of the control system, K is a gain constant, S is the Laplace transform, and α is the percentage of acceleration control. In this experiment α was .50. Because the control system was neither a pure rate system nor a pure acceleration system, it is difficult to provide a single value for gain output of the control stick. However, if α were equal to zero in Equation 1 (pure velocity control), the gain output at maximum stick pressure would not have exceeded 21.2 cm/sec. If α were equal to 1.0 (pure acceleration control), the gain output at maximum stick pressure would not have exceeded 37.3 cm/sec.

After training and a 5-min rest, each subject performed the 7-min transfer task which was similar to the training task except that no performance information was provided. During transfer the difficulty of the task changed after each minute of tracking. Three levels of difficulty were presented: the exit criterion in training (.55 Hz), one more difficult than the exit criterion

(.65 Hz), and one less difficult than the exit criterion (.45 Hz). The order of task difficulty presented was counterbalanced across the subjects in each training condition using a Latin square.

Equipment. The equipment interfaces in the experimental situation involved a Raytheon 704 digital computer which generated inputs to a cathode-ray tube display and processed signals from a two-button keyboard and a manual controller. The computer provided digital signals to a symbol generator which converted them to analog for display on a 7.6-x-10.2-cm Hewlett-Packard (Model 1300A) cathode-ray tube. A two-finger isometric controller, requiring ±1.4 kg full-scale pressure, was used. Although an isometric controller does not provide a distance cue to facilitate accurate positioning, it is advantageous for the rapid movement necessary to track a higher-order control system (Poulton, 1974). To increase control-display compatibility and to reduce control reversals in the Y-axis, both the controller and the display were tilted slightly so that control movement would be in the same plane as display movement.

The software program used involved two real-time cycles — a 20-msec refresh cycle and a 60-msec cycle to calculate new information from the keyboard and the controller. Subject data were temporarily stored on disc and then transferred to magnetic tape at the end of each trial.

Subjects. A total of 36 subjects participated in the experiment. Of these, six males and six females were randomly assigned to each of the three training conditions. The subjects were university students who volunteered for the experiment and were paid $5.00 each for their participation. All were nonpilots, naive to the experimental task, and right-handed.

Results

Training. The dependent variable of interest in training was the time required to reach the exit criterion. A two-factor analysis of variance, with training type and sex as factors, was conducted on the time-to-exit scores. A reliable main effect of sex, $F(1,30)=12.14$, $p<.001$, was revealed. On the average, males required approximately 9 min to reach the exit criterion, whereas females required more than twice as much time (approximately 20.5 min on the average).

Mean training times (in minutes) by sex and training type are given in Table 1. For female subjects, lower mean training times were obtained using an adaptive training system, either automatic or learner-centered. However, neither the training type main effect nor the training type x sex interaction was reliable in the analysis of variance ($p>.05$). The failure to find a reliable training-type effect with female subjects may have been the result of a relatively small sample size and/or the large variability in performance among female subjects. The SD of training time scores for females was 13.1 min as compared to 5.4 min for males.

Table 1
Training Time to Exit (min)

	Males		Females	
Training Type	$\bar{X}$	SD	$\bar{X}$	SD
Fixed-difficulty	8.0	3.7	27.2	14.3
Automatically-adaptive	9.0	2.5	18.1	13.1
Learner-centered	9.7	8.8	16.2	11.2

Transfer. Vector root-mean-square (RMS) error was integrated over each minute of tracking during transfer. A three-factor analysis of variance on vector RMS error, with training type, sex, and level of difficulty as factors, was conducted.

The main effect of level of difficulty was reliable, $F(2,60)=88.79, p<.001$, indicating that the three different band limits for frequency of the forcing function used in transfer provided tasks of uniquely different levels of difficulty. As expected, tracking error increased when the low-pass, band-limited filter was set at higher levels (12.2%, 16.1%, and 19.5%, respectively). During training the exit criterion for tracking accuracy was 14%.

The main effect of training type was also statistically significant, $F(2,30)=3.99, p<.05$. A subsequent Newman-Keuls analysis indicated that the reliable comparison was between the students trained in the fixed-difficulty condition and those trained in the learner-centered condition. Vector tracking error in transfer for students in the learner-centered condition across all three levels of task difficulty was on the average 15.2% of the screen diagonal as compared to 17.3% for students trained in the fixed condition.

In terms of sex differences, the highly reliable difference in tracking performance between males and females in training was absent in transfer. No reliable differences in tracking error between males and females were found in transfer ($p=.48$). This is especially noteworthy for the highest level of tracking difficulty (forcing function filter at .65 Hz) which exceeded the maximum level of task difficulty during training.

Difficulty shifts. An analysis of difficulty scores comparing the last 15 sec of each task-difficulty section in transfer to the first 15 sec of the following section yielded no reliable differences ($p>.10$) by training type or sex, indicating that the subjects had relatively the same difficulty or ease of transitioning among the various sections of the transfer task. These data fail to support earlier research by Gopher, Williges, Williges, and Damos (1975) which yielded strong support for the contention that adaptive training facilitates the adjustment of subjects to changing conditions.

Vertical versus horizontal axis. An analysis of variance of X-axis and Y-axis tracking error indicated that performance on the X-axis was significantly superior, $F(1,30)=28.14$, $p<.0001$, despite attempts to maximize display-control compatibility in the equipment setup. This result supports the need for research on the effects of independent manipulation of tracking axes in adaptive training (see Gopher et al., 1975).

Discussion

Sex differences. Evidence for differences in tracking skill in adults favoring males has been presented by Ammons, Alprin, and Ammons (1955), Noble (1970), and Noble and Noble (1972). Yet each of these studies share certain characteristics that set them apart from the present study. First, none of these earlier studies was a training situation in terms of defining a behavioral objective and measuring time necessary to attain that objective. In all cases, every subject was given a specified number of trials, and time-on-target on these trials was measured. Second, the experimental task in each study was the rotary pursuit, and the dependent measure was time-on-target. Bahrick, Fitts, and Briggs (1957) pointed out that using a dependent measure which requires an "arbitrary choice of a cutoff point in the dichotomizing of a continuous response distribution can impose significant constraints upon the shape of the resulting learning curves" (p. 256). Time-on-target scores are insensitive to changes in level of performance outside the designated target region. Therefore, even large improvements in performance outside the target zone are not reflected in time-on-target scores. Kelley (1969a) summarizes this argument by stating that, because time-on-target scores are not equal-interval measurements, they cannot legitimately be summed, averaged, or used to present learning curves. Therefore, time-on-target is an inappropriate measure of performance over an extended period of time, particularly if the ranges in error amplitude vary dramatically among various groups of subjects.

In the present study, the highly reliable sex difference reflected in training time was nonexistent during transfer. Particularly important is the failure to find a sex difference in transfer when task difficulty was increased to a level higher than that required during original training. This would indicate that, although women may require some additional training time

initially on a motor-control task similar to the task used in this study, no performance differences by sex could be expected once training is accomplished.

It is interesting to hypothesize why the sex difference was revealed in training. Ammons et al. (1955) suggested that basic skill proficiency is a combination of fundamental ability and transferred skill. Presuming that fundamental abilities are equal, this would imply that females learn fewer motor skills and less well than males.

Research by Noble, Baker, and Jones (1964), who studied simple discrimination reaction time for both sexes at various ages, supports this notion. These researchers found no differences in response speed between males and females up to the age of about 16 yr. However, after age 16, female performance began a fairly linear decline, whereas male performance improved until age 20 when it too underwent a progressive decline.

The sex difference revealed in the present study may very well reflect only a difference in prior experience with similar motor-control tasks. To test this hypothesis, an analysis of variance on vector error for the fixed-difficulty group in the first 3 min of training was conducted; this analysis resulted in a reliable sex difference, $F(1,10)=9.45$, $p<.05$. At least in the fixed-difficulty condition, males and females were not equated in terms of initial performance. Additional research is needed to investigate the sex versus prior experience influences.

Adaptive logic. Much effort has been expended in an attempt to optimize the human-learning model. Two approaches have been taken. Some investigators have sought the optimum training model to be used for all individuals. Their research has involved questions such as: when should changes in terms of difficulty in the training program be made; what should be the magnitude of these changes; should stimulus inputs or performance standards be changed. However, it is difficult to develop a single learning model which will allow for the previous experience, aptitude, and motivational level of a variety of students. A second approach involves a search for a means to measure aptitude and personality variables which will affect learning and then apply these measures to the selection of appropriate training material and teaching strategy for each student. Unfortunately, the bases for forecasting performance are not well established.

A third approach was examined in the present study where the student was given the opportunity to establish his own decision rules for training. These results indicate that the student is quite capable of effectively manipulating the learning situation based on his own internal training model. One could argue that learner-centered instruction fared so well only because the computer learning algorithm used was unsophisticated and, therefore, suboptimal for the task to be learned. However, until more sophisticated logic schemes are developed and evaluated, the training designer might be well-advised to consider a learner-centered approach to individualize motor skills training.

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Submitted June 7, 1977
Revision submitted September 16, 1977

Erratum

The following figure should have appeared in the paper by Williges and Williges (*Journal of Motor Behavior*, 1977, 9, 325-331) on Page 327 rather than the Figure 1 that did appear.

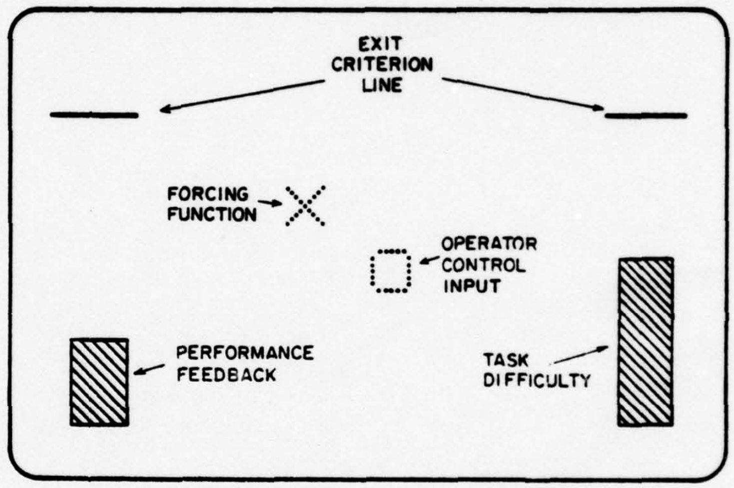

Fig. 1. Pursuit tracking display indicating the forcing function and operator control input symbols, the feedback bars, and the exit criterion lines.

Appendix B

Critical Variables in Adaptive Motor Skills Training

HUMAN FACTORS, 1978, 20(2), 201—214

Critical Variables in Adaptive Motor Skills Training

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Automatic adaptive training procedures for motor skills learning have been suggested for several years. Adaptive training is a closed-loop system in which some aspect of the student's performance is monitored and used in a computer algorithm to adjust the difficulty of the training task. Only limited research exists on the evaluation of these procedures both in basic laboratory motor learning tasks and in applications to flying training using synthetic flight trainers. In this paper critical variables dealing with the performance measurement procedure, the choice of the adaptive variable, and the appropriate adaptive logic are evaluated. The results of a series of laboratory studies are reviewed, and several suggestions for additional research as well as a general model of instruction are discussed. It was concluded that the most effective automated adaptive motor skills training probably should use multivariate performance measurement schemes which manipulate stimulus-related adaptive variables in connection with a closed-loop adaptive logic model that is optimized for individual differences.

INTRODUCTION

Through the use of modern computer technology, it is now feasible to consider the implementation of automatically adaptive procedures in a variety of human factors problem areas. Adaptive procedures are characterized by the automatic change in one or more classes of variables, the adaptive variables, according to some computer logic scheme. The changes in the adaptive variable(s) are based on the subject's performance which is continually monitored. Hudson (1969) proposed using these procedures as an economical way of conducting multiparameter research in human factors. The computer would constantly compare its polynomial regression model of predicted output to the subject's response and adaptively change the computer model until some convergence of the computer model and subject output is obtained. Ince and Williges (1974) used adaptive procedures to determine how well the human operator detects slow changes in system dynamics. Measures of attention to predict success in pilot training were developed by North and Gopher (1976) using adaptive procedures. Cross-adaptive procedures as discussed by Kelley and Wargo (1968) have been used by Damos (in press) for investigating workload. Through the use of cross-adaptive procedures, the level of difficulty on one task, the secondary task, is increased automatically once performance on the other task, the primary task, is within tolerance. Adaptive computer aiding using dynamic utility estimation has been success-

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fully applied to computer-aided controls (Steeb, Weltman, and Freedy, 1976) and to decision aiding (Leal, Shaket, Gardiner, and Freedy, 1977). In adaptive testing (Hansen, Ross, and Harris, 1977) the computer removes test items which are too difficult or too easy. And, finally, Atkinson (1976) discussed the use of adaptive procedures in optimizing instructional strategies in computer-based systems.

However, the first and perhaps most popular use of automatic adaptive procedures is in the area of motor skills training. Hudson (1962) noted anecdotically that much of his early training time learning to fly a helicopter was spent waiting while the instructor pilot brought the vehicle back under control. He reasoned that his instruction time would be more benefical and efficient if the stability of the craft could be changed adaptively to adjust to the current skill level of the student pilot thereby reducing both the risk of losing control of the helicopter and the amount of training time relegated to watching the instructor pilot regain control.

The present use of the term adaptive training often refers to a motor learning task in which the difficulty or complexity of the training task varies directly as a function of how well the trainee is performing. If the trainee is within a specified error tolerance, the task difficulty or complexity increases until an exit criterion is reached. If, on the other hand, the trainee is outside a specified error tolerance, the task difficulty is decreased. Kelley (1969a) summarized an adaptive training system as requiring a continuous measure of trainee performance, one or more adaptive variables that can change the task difficulty or complexity, and a logic system for automatically changing the adaptive variable(s).

Following reports by early investigators such as Kelley and Hudson, interest quickly developed in the use of automatically adaptive techniques as a means of providing efficient psychomotor skills training. Several preliminary applications of these procedures to complex synthetic flight trainers have been attempted. For example, Lowes, Ellis, Norman, and Matheny (1968) adaptively varied the amount of turbulence in a Universal Digital Operational Flight Trainer Tool; Caro (1969) discussed the use of adaptive techniques in the Synthetic Flight Training System used in helicopter training; and Brown, Waag, and Eddowes (1975) presented a preliminary evaluation of adaptive procedures used in ground controlled approach training in an F-4 Automated Flight Training System. However, not all research supports the superiority of adaptive training for motor skills (see Lintern and Gopher, 1977, for a review), and it is these conflicts which point toward research needed to optimize individualized motor skills training.

Fundamental investigations of critical variables need to be completed before more precise statements can be made about the utility and limitations of using computer-adaptive procedures in motor learning tasks. The purpose of this paper is to review a series of laboratory research efforts directed toward a clearer understanding of the choice of the performance measurement scheme, the adaptive variables, and the adaptive logic. Additionally, the results of these related studies suggest some research needs as well as implications for a general model of instruction.

LABORATORY TRACKING TASK

The specific data reviewed in this article pertain to a series of research studies which used the same general training and transfer tasks. These tasks were generated by a digital computer which provided inputs to a cathode-ray tube display and processed control outputs from an analog control stick. The specific details of the hardware/software system for task generation varied somewhat

across the studies, and these details are presented by Gopher, Williges, Williges, and Damos (1975), Williges and Williges (1977), and Williges, Williges, and Savage (1977).

Training Task

Each subject completed a series of 3-min tracking trials to learn a two-dimensional pursuit tracking task in which two random, band-limited functions were used to determine the x-y coordinates of the forcing function symbol "X" on the display. The control output "O" was generated using inputs from the analog controller. Figure 1 shows the most recent version of the task in which dynamic, augmented performance feedback was presented in addition to the forcing function and controller symbols used in the pursuit tracking task. One feedback bar (the right vertical line in Figure 1) depicted the current level of task difficulty in relation to the exit criterion level of difficulty (the right horizontal line on Figure 1). The left feedback bar showed a smoothed measure of current tracking accuracy in relation to both the acceptable level of accuracy required by the adaptive logic and perfect performance (the left two parallel lines on Figure 1). In other words, when the vertical line depicting tracking accuracy was within the tolerance allowed, the task difficulty vertical line increased. Conversely, the task difficulty decreased when tracking accuracy was out of tolerance. This procedure continued until the subject was able to perform the pursuit tracking task while maintaining both feedback bars at or above the exit criterion lines continuously for a specified period of time.

Several variables in the task were programmed to serve as potential adaptive variables in manipulating task difficulty. Three such variables were used across the studies reviewed in this article. One variable was the change in the band limits of the random functions determining the x-y coordinates of the

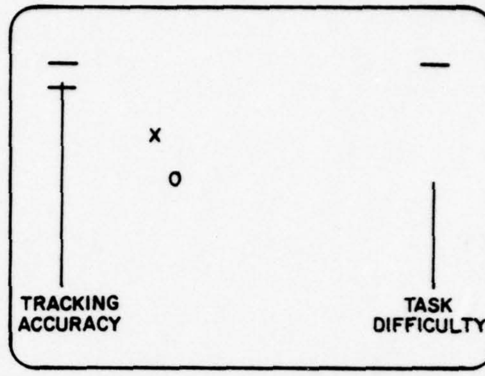

Figure 1. *Two-dimensional pursuit tracking task with adaptive logic and augmented feedback indicator.*

"X" symbol in the pursuit tracking task. A second adaptive variable was the gain output of the control stick which was increased relative to the effective size of the display. And, the third variable was the manipulation of the weighting of the second-order term for the control output "O" as determined by the formula,

$$\theta_0 = (1-\alpha)\frac{K}{S} + \alpha\frac{K}{S^2} \qquad (1)$$

where Θ_0 equals the weighted order of the control system, K is a gain constant, S is the Laplace transform operator, and α is the percentage of acceleration control.

Transfer Task

Following a short rest period, each subject in all the studies completed a transfer task which was a 7-min tracking session similar to the training task except that no augmented feedback information was provided. During transfer the level of difficulty of the task changed automatically after each minute of tracking. Three levels of difficulty were used: the same as the exit criterion in training, more difficult than the exit criterion, and less difficult than the exit criterion.

PERFORMANCE MEASUREMENT

Any adaptive training paradigm is based on an automated performance measurement system. Before the adaptive variable can be manipulated by the adaptive logic, a continuous online measure of operator performance is required in the motor skills task. Usually this performance measure is some indication of tracking error. Even in simple, one-dimensional tracking tasks, the researcher must choose between a variety of measures, such as time on task, average absolute error, and root mean square error (RMS). As the number of tracking dimensions increases, the investigator must choose between separate, single-axis scoring for the adaptive procedure or some type of combined-axes scoring such as averaging, largest-error score, or vector scores. (Kelley 1969b provides a detailed description of these various scoring procedures.)

Research by Gopher, Williges, Williges, and Damos (1975) vividly depicts dimension differences in a two-dimensional, pursuit tracking task which varied according to an adaptive logic. The horizontal and vertical dimensions adapted separately according to RMS errors in each dimension. Figure 2 clearly shows that the adaptive variables adapted to higher levels in the horizontal dimension than in the vertical dimension over the same period of time. Obviously, a combining procedure which either underestimates or overestimates one dimension can cause the adaptive logic to change the difficulty of that dimension at an inappropriate rate with regard to the real momentary level of proficiency in that dimension.

The difference in rate of adaption in the two dimensions of the Gopher, Williges, Williges, and Damos (1975) study may be a function of the compatibility of the control-display arrangement (Fitts and Posner, 1957). Tracking in the vertical dimension was paired with the fore-aft movement of the control stick in an orthogonal dimension, whereas movement in the horizontal dimension was compatible with the right-left movement of the control stick. Subsequent research by Williges and Williges (1977) involved a tilted display surface and controller to eliminate the orthogonal arrangement. Even this correction did not eliminate the differential transfer effects across the two dimensions. In the Williges, Williges, and Savage (1977) study, the same differences were obtained with the display and control untilted. Table 1 shows significantly larger RMS tracking error ($p < 0.05$) in the vertical as compared to the horizontal dimension across each level of transfer task difficulty in the data collected in both Study 1 (Williges and Williges, 1977) and Study 2 (Williges, Williges, and Savage, 1977). Training in both of these studies, however, was conducted using an adaptive logic based on vector RMS error of the two tracking dimensions. These vector calculations permit error in one dimension to be compensated for by more accurate performance in the other dimension.

Research Implications

Even in the case of laboratory tracking tasks using adaptive logic, several research issues need investigation. In multidimensional tracking, the approach of adapting each dimension separately or simultaneously needs to be evaluated. The effect of various procedures for combining dimensions in adaptive training also needs further research to isolate and document various measurement biases and tradeoffs among these approaches. In addition, Norman (1973) and Ricard and Norman (1975) demonstrated that the performance measurement interval can also affect the rate of adaption. They suggested an optimum interval for a roll-control task, but this optimum may vary among different tracking tasks.

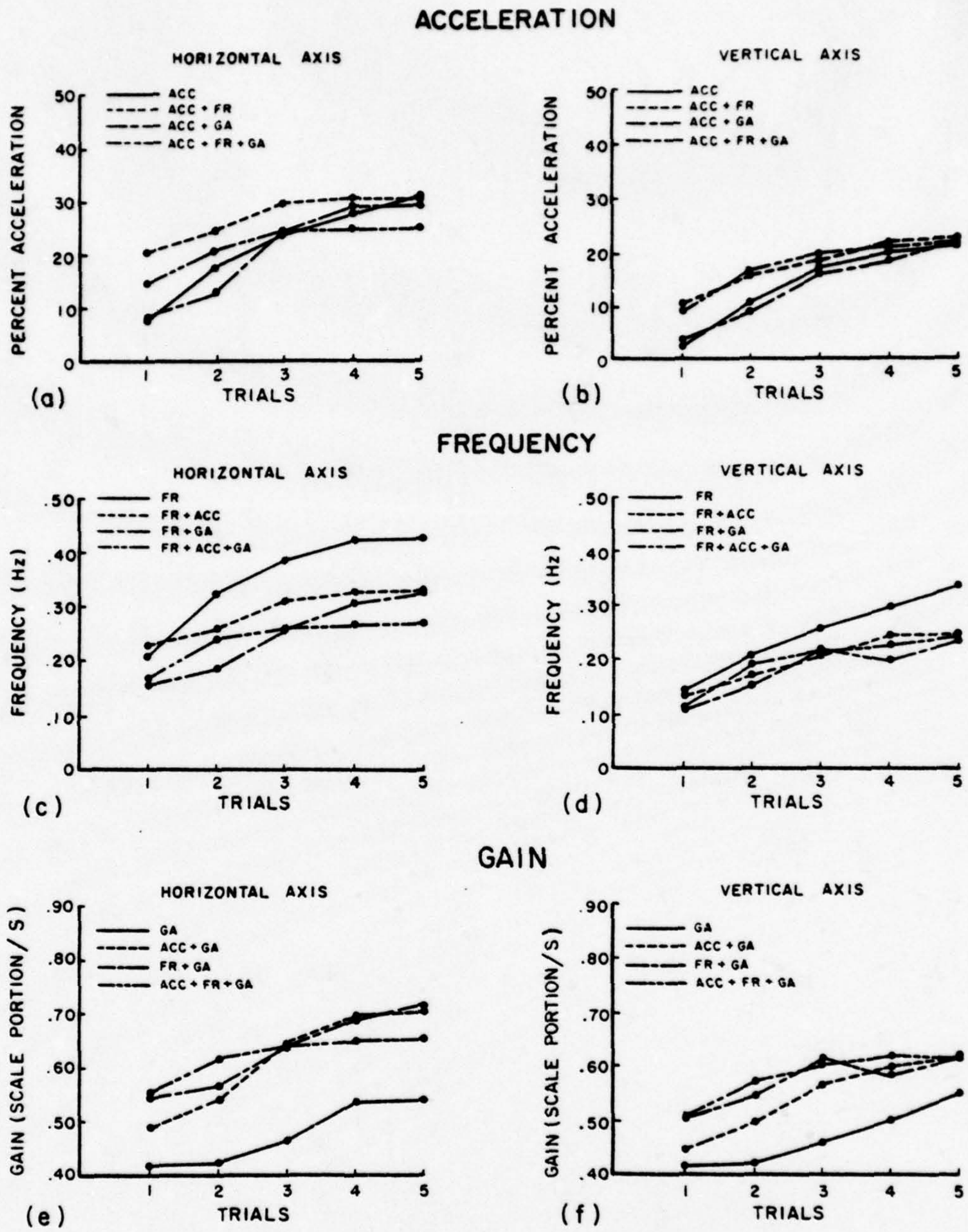

Figure 2. *Average levels of adaptive variables during each 3-min training trial (Adapted from Gopher, Williges, Williges, and Damos, 1975).*

TABLE 1

RMS Tracking Error in Transfer by Axis and Task Difficulty (Percent of Scale)

Axis	Task Difficulty		
	Low	Medium	High
	Study I		
Horizontal	8.02	10.55	13.01
Vertical	8.92	11.68	14.13
	Study II		
Horizontal	4.54	7.15	9.19
Vertical	5.47	8.01	10.73

Once adaptive procedures are extended to operational tracking environments, such as flying an aircraft, the performance measurement considerations become even more acute. In an aircraft a variety of pilot task and systems variables combine to determine the resulting performance measures. For example, Vreuls, Wooldridge, Obermayer, Johnson, Norman, and Goldstein (1975) measured 18 pilot/system variables (e.g., elevator stick force, angle of attack, airspeed, roll attitude, sideslip, etc.) every 0.15 s in a flight simulator which incorporated adaptive logic. Three different combining procedures for the resulting performance measurement used in the adaptive logic were evaluated. These combining procedures included a simple, composite scaling method based on one assumed distribution score, a normative scale based on empirically derived distributions for each separate flight maneuver distribution, and a set of weighting coefficients based on a discriminant analysis which combined the best set of pilot/system variables that discriminated between early and late training performance. Both the measures based on the normative scale and the discriminant analysis weightings resulted in reduced training time on the adaptive simulator system as compared to the original composite score. Additional multivariate measures such as these need to be developed before meaningful operational use of adaptive procedures occurs in complex simulator environments.

ADAPTIVE VARIABLES

Another important consideration in adaptive training is the choice of the adaptive variable used to manipulate task difficulty. Several variables have been used. Most aircraft simulator applications of adaptive training procedures have manipulated variables related to turbulence (e.g., Lowes, Ellis, Norman, and Matheny, 1968, and Brown, Waag, and Eddowes, 1975). Laboratory tracking task investigations, however, have manipulated various adaptive variables, such as system stability (Hudson, 1964); damping ratio (Gaines, 1967); the gain effective time constant product, system compensation, and forcing function in a single-axis tracking task (Norman, Lowes, and Matheny, 1972). Little systematic research, however, has been conducted to provide a basic understanding and rationale for the appropriate choice of the adaptive variable.

To provide a perceptual-motor task with sufficient dynamic range of performance that would allow systematic differences in speed of learning to be measured reliably, Crooks and Roscoe (1973) chose to vary the ratio of acceleration to rate output of the control system as defined in Equation 1 as the adaptive variable. The general result of their study was that automatic adaption of task difficulty hindered rather than facilitated learning as compared to a fixed difficulty, conventional training procedure. It was hypothesized that this finding occurred because of the nature of the adaptive variable.

In the Crooks and Roscoe (1973) study, as the subject practiced the task and error decreased, the ratio of acceleration to rate output of the control system varied. As the con-

trol system changed, a response appropriate only a moment ago for one control system configuration was no longer correct. Consequently, the subject had the additional problem of continually adjusting his response strategy in the adaptive training condition as he proceeded toward the exit performance criterion. Generalizing from Osgood's (1953) transfer surface developed in verbal learning, one can postulate that changing of response strategies to similar stimuli should result in an inhibition paradigm and destroy any advantages of adaptive training.

To test the hypothesis that certain adaptive variables inhibit learning, an experiment was conducted by Gopher, Williges, Williges, and Damos (1975) to compare the response variable of ratio of acceleration to velocity control as an adaptive variable to two other adaptive variables. These variables were adapting the gain of the control stick, another response variable, and adapting the band limit of a low-pass filter, a stimulus variable analogous to frequency of the forcing function. In addition, the experiment examined situations in which more than one of these variables was adapted simultaneously.

The training results are summarized in Figure 2 showing several reliable effects ($p < 0.05$). Essentially, the highest rate of adaption in the frequency variable occurred when frequency was the only adaptive variable, and no response-related variables were adapted. The rate of adaption in acceleration was greater early in training when frequency, the stimulus variable, also adapted; more adaption occurred in gain when other variables also adapted. During transfer, subjects trained adaptively generally showed more stable performance in the changing task situation than the subjects trained under fixed difficulty ($p < 0.05$), but no reliable differences among conditions appeared in retention ($p > 0.05$).

In general, these data tend to support a conclusion that stimulus-related rather than response-related variables are recommended in adaptive training. Certainly, the highest rate of adaption as shown in Figure 2 occurred when the stimulus variable (forcing-function frequency) was the only adaptive variable. In addition, the rate of adaption in the two response-related variables (gain and percent acceleration control) was enhanced when the stimulus variable was also changed. Interpreting the effect of the number of variables adapted simultaneously is, however, not as straightforward because the study consisted of only one stimulus variable and two response related variables. The general tendency shown in Figure 2 is that the highest rate of adaption of the stimulus variable, frequency, seems to occur when only one variable at a time is adapted. As more variables are adapted simultaneously, the rate decreases. In the case of the response variable, control stick gain, additional variables adapting simultaneously increases the rate of adaption.

Research Implications

The Gopher, Williges, Williges, and Damos (1975) study provides some empirical evidence that a possible underlying relationship to consider in choosing an adaptive variable is whether the variable is stimulus or response related. Initial indications seem to suggest that the rate of adaption is enhanced through the use of a stimulus-related variable. This finding needs to be extended to other stimulus variables, and possible transfer effects need to be more clearly defined. In addition, the effects of type of adaptive variable and number of adaptive variables need to be separated through factorial manipulation so that separate as well as interacting effects can be determined.

ADAPTIVE LOGIC

Choice of the adaptive logic scheme is perhaps the crux of any adaptive training

situation. The original formulation by Hudson (1962) was a logic scheme in which the level of difficulty of the adaptive variable increased as the level of error decreased. Alternatively, Kelley (1969a) proposed using a time derivative, or rate of change, of the adapttive variable associated with the performance measure. In other words, the Hudson logic requires both the accuracy of performance and the level of the adaptive variable to change during training; whereas, the Kelley logic maintains performance within a certain tolerance, and the adaptive variable changes during training.

Any consideration of the particular logic scheme in adaptive motor skills training includes not only the general form of the logic itself, but also the effects of several additional variables. For example, Norman (1973) and Ricard and Norman (1975) demonstrated a relationship between the performance measurement interval used in the adaptive logic and the training task characteristics which are adjusted. Only limited data exist on the positive effects of augmented feedback (Kelley, 1969a, and Norman, 1973) and the effect of step size, the amount of increase or decrease in the level of difficulty of the adaptive variable (Kelley, 1969a). These considerations have, in turn, led to alternative logic schemes, such as a system-theoretic approach relating training to control of an abstract dynamic system (Gaines, 1974), discrete as opposed to continuous changes in difficulty (Wood, 1969), changing error rates required for adaption (Crooks and Roscoe, 1973), and differing rates of increasing and decreasing task difficulty (Norman, 1973).

When one considers applications to synthetic flight trainers, the adaptive logic would most likely manipulate level of difficulty on a particular flight syllabus. For example, Wooldridge, Vreuls, and Norman (1978) made a preliminary investigation of eight different training methods used to teach seven different instrument flight maneuvers including, in order of related difficulty, straight and level, climbs and dives, climbs and dives with reversals, turns, turns with reversals, climbing and diving turns, and climbing and diving turns with reversals. Within each of these maneuvers the syllabus consisted of eight steps of difficulty including various combinations of initial airspeed, angle of turn, rate of climb or descent, fore or aft center of gravity of the aircraft, and the presence or absence of turbulence. The eighth level of difficulty was considered the criterion level for each maneuver. In other words, this type of motor skills task can be characterized as a large step logic paradigm in which various logic schemes can be used to step the student through the training syllabus. The seven logics investigated by Wooldridge, Vreuls, and Norman (1978) include: three adaptive logic schemes that based progression on both current and prior performance; an adaptive logic scheme that provided for progression in two dimensions, either to a new task or to a new task stressor; two remedial branching strategies; and random exercise presentation. Each of these was compared to traditional training by an instructor who used the same approach with all students.

Regardless of the specific variables used in the adaptive logic, the logic scheme can be viewed as one of possibly several general models of motor skills training. By evaluating the general characteristics of these models rather than the models themselves, implications can be drawn for the design of efficient adaptive logic systems for specific applications.

Models for Automated Motor Skills Training

The traditional approach to motor skills training is a fixed-difficulty model in which students are initially presented the criterion task and their error decreases as training

progresses. Unfortunately, this model has no provision for individual differences in prior experience and rate of learning thereby often making the training task too easy at times for some individuals and too difficult at times for others.

Adaptive training techniques provide a method for individualizing motor skills instruction. Using a closed-loop model in which some aspect of the student's performance is monitored and a logic system is used to adjust the difficulty of the task, the adaptive techniques optimize training by individually adjusting task difficulty for a wide range of skill levels. But, the usual approach taken in adaptive procedures is to use only one logic system for all individuals with the implicit assumption that there is one optimum logic for all individuals. Even though this one logic system will provide a variety of individual task difficulty profiles, it may not provide enough flexibility.

The antithesis of this computer-controlled approach puts the control of the lesson strategy in the hands of the student (Fry, 1972; Lahey, Crawford, and Hurlock, 1976; Mager and Clark, 1963). Students directly determine changes in task difficulty. The learner-centered model has two primary advantages. First, learner-centered instruction is economical to develop because elaborate logic schemes for selecting content or sequence are unnecessary. Second, students using learner-centered instruction learn to evaluate their own performance and thereby develop their own internal feedback mechanism. The most straightforward way to implement the learner-centered approach is to make the motor skills task manually adaptive by providing a switch which allows the students to increase or decrease the level of difficulty as they wish. (Details for implementing this procedure are discussed by Williges and Williges, 1977.) Students, thereby, provide their own training strategy as compared to one computerized logic scheme present in an automatically adaptive training situation.

Two studies were conducted to evaluate the relative effectiveness of various training models as well as the influence of individual differences attributable to the sex of the student. The first study was reported by Williges and Williges (1977), and preliminary data from the second study are discussed by Williges, Williges, and Savage (1977). The second study involves an open-loop training model, the shifting-difficulty model, which was a strategy adopted voluntarily by many subjects in the learner-centered model tested by Williges and Williges (1977). In the shifting-difficulty model, task difficulty is initially set at a low level so that the student learns to use the system; then after a short period of time (one 3-min trial) task difficulty shifts to the criterion level so that the student learns the specific task. This model is not individualized in that the feedback loop is not present; i.e., the shift occurs regardless of student performance.

Table 2 compared the transfer RMS error from the first study (Williges and Williges, 1977) with the final results of the second study. Two prominent effects are present. First, there is a marked effect of sex of the student as evidenced by less tracking error ($p < 0.01$) for males than females in the second study. It occurred even after both sexes were trained to the same criterion level of performance. This result disagrees with the results of the first study which revealed no sex differences in transfer tracking error ($p > 0.05$). Because an attempt was made in the second study to match males and females on tracking proficiency prior to training, these differences certainly need to be investigated in more detail to determine whether additional training or a different type of training would erase the sex difference. In both of these studies, however, there was no statisti-

TABLE 2

Overall RMS Tracking Error in Transfer by Sex and Training Condition (Percent of Scale)

Training Condition	Sex	
	Male	*Female*
Study I		
Learner Centered	15.38	14.99
Adaptive	16.51	15.83
Fixed Difficulty	17.48	17.20
Study II		
Adaptive	9.03	11.69
Fixed Difficulty	10.55	11.73
Shifting Difficulty	10.89	11.53

cally reliable sex by training condition interaction ($p > 0.05$).

Training conditions, which represented different training models, resulted in reliable differences in transfer tracking error across both studies ($p < 0.05$). Subsequent Newman-Keuls analyses ($p < 0.05$) showed lower RMS error for the students in both the learner-centered and adaptive training conditions as compared to the fixed difficulty training condition in the first study, and the adaptive condition in the second study resulted in less RMS tracking error than either the fixed difficulty or shifting difficulty conditions.

Interestingly, it appears that a closed-loop training model results in better transfer than an open-loop model in both studies. The learner-centered and the adaptive training models are both closed-loop type models in the first study, whereas only the adaptive training condition is closed-loop in the second study. It would appear that future research in motor skills training should not be concerned with comparisons of open- versus closed-loop models; rather the concern should be with optimizing a closed-loop model for teaching motor skills. The feedback loop can either be applied automatically through adaptive logic schemes or directly by the learner in a learner-centered model. In that the learner-centered model fared so well in the Williges and Williges (1977) study, a training designer might be well-advised to consider a learner-centered approach (if it can be implemented without substantially increasing the workload of the student) until more sophisticated automatic logic schemes are developed.

Research Implications

Several research issues still need to be evaluated in terms of the adaptive logic. Despite the fact that skill training is individual rather than a group experience, a fixed logic system is usually considered for adaptive systems. Lintern and Gopher (1977) suggested that changing adaptive equations across training as opposed to one fixed adaptive logic scheme throughout training needs to be investigated experimentally. Atkinson (1976) even proposed that adaptive logics may change as performance records of students using the system identify more beneficial instructional strategies.

Research also is needed on the pairing of individual styles of motor learning with the compatible logic schemes. Recent work by Pask (1976) on cognitive tasks indicates that the matching of the instructional strategy and individual characteristics is a critical factor in maximizing training. Pask's research points out that when the student's preferred learning style and teaching strategy are mismatched, learning is severely disrupted in terms of comprehension and retention. Conway and Norman (1974) proposed a self-organizing training system which has the capability of identifying different learning styles based on both a performance profile and an individual history of the trainee. They suggested that some of the candidate history parameters for determining individual differences include previous experience, personal-

ity characteristics, cognitive components, psychomotor ability, and the trainee's social and educational background. Subsequently, some of these concepts were implemented in the development of a higher-order, partially self-organizing adaptive flight training system with a real-time perspective cathode ray tube display (Vreuls, Wooldridge, Conway, Johnson, Freshour, and Norman, 1977). Additional research is needed to determine the specific dimensions of individual differences that are associated with various adaptive logic strategies.

Most adaptive logic schemes are not based on existing human learning models. Chatfield and Gidcomb (1977) suggested that many of these models may be used to formalize the logic in higher-order adaptive systems which are tailored to individual differences. These models can be used to describe the student's performance so that the adaptive logic can select strategies on the basis of hypothesized learning states of the individual. Specifically, they suggest that Markovian models similar to techniques presented by Wollmer (1976) may be appropriate for adaptive motor skills training. These procedures, however, still need to be refined and evaluated in an adaptive training context.

Another important issue deals with the role of augmented feedback in adaptive logics. The Kelley (1969a) adaptive logic system minimizes the usefulness of intrinsic task feedback. By manipulating task difficulty based on performance, a relatively constant level of error is maintained over time. Consequently, the student sees no progress in terms of error and needs augmented feedback in terms of the level of task difficulty. The Hudson (1962) logic system, on the other hand, contains a great deal of useful intrinsic feedback because as the difficulty of the task increases, error decreases, which is fairly obvious to the student learning a pursuit tracking task. The requirement for augmented feedback clearly differs in these two systems, and the role of such feedback needs to be evaluated. In addition, the optimal technique for withdrawal of augmented feedback during training needs to be investigated in order to maximize transfer and retention. Consideration should be given to withdrawing feedback adaptively (analogous to fading in programmed instruction) to minimize the performance decrement in transfer. One potentially promising procedure is to manipulate augmented feedback adaptively. Lintern (1977) demonstrated that students trained on a computer-generated visual landing system using adaptively presented guidance cue feedback reached transfer criterion performance quicker than either the continuous guidance cue feedback group or the control group which received no augmented feedback.

Closely tied to the specific manipulations of the feedback variables are the possible interactions of feedback with various adaptive logic constraints. The type of overall adaptive logic structure, such as the Hudson (1962), the Kelley (1969a), shifting difficulty, preprogrammed increase, learner-centered manually adaptive, and open-loop fixed difficulty systems, needs to be investigated. Other adaptive logic variables and their interaction with feedback requirements should be experimentally evaluated. Some of these adaptive logic variables include starting the adaptive training at the exit versus minimum level of difficulty, allowing the difficulty level to exceed or not exceed the exit criterion, having differing adaptive rates for increasing and decreasing difficulty, and providing deadbands in the automatically adaptive logic in which no changes in task difficulty occur. All of these investigations are required to provide the necessary data base before sophisticated and cost-effective adaptive logic schemes optimized for individual differences can be developed.

CONCLUSION

From the results reviewed in this paper, it seems that effective motor skills training should involve multivariate performance measurement schemes which manipulate stimulus-related adaptive variables in connection with closed-loop adaptive logic models that are optimized for individual differences. However, even though the concept of adaptive training has been touted for several years, there is a dearth of unequivocal evidence for its training utility. In fact, experimental data on many of the critical variables discussed by Kelley (1969a) are still not available. Fundamental research on these issues is needed both to develop a comprehensive theory of motor learning and to design operational training systems to optimize training, transfer, and retention of motor skills.

ACKNOWLEDGMENTS

This article is based, in part, on a paper presented at the 6th Congress of the International Ergonomics Association in July, 1976. Contractual support for this paper was provided by the Life Sciences Program, Air Force Office of Scientific Research, Grant Number 77-3161. Captain Jack A. Thorpe served as the scientific technical monitor.

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Appendix C

Individual Differences in Motor Skill Training

Proceedings of the Sixth Psychology in the DoD, April, 1978.

INDIVIDUAL DIFFERENCES IN MOTOR SKILL TRAINING

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Fifty-one males and 39 females were given five paper-and-pencil tests (spatial scanning, visual memory, perceptual speed, spatial orientation, and perceptual style) and a motor skill test to develop regression equations that predict training time for a two-dimensional pursuit tracking task. One of three training conditions (fixed difficulty, adaptive, shifting difficulty) was randomly selected for each subject. Regression equations for the different training conditions accounted for as much as 87% of the variance in training time. Results are discussed in terms of predicting an optimal training condition for the individual.

Recent interest in the relationship between information processing skills and motor skills may have implications for investigating individual differences in motor learning. Marteniuk (1976) states that there are three basic information processing mechanisms involved in any motor skill: the perceptual, decision, and effector mechanism. Much of the emphasis in his discussion of information processing in motor skills is that limitations in any of these mechanisms can limit motor performance. If these perceptual or cognitive processes can be measured to determine differences in capacities, then individual differences can be studied as they relate to motor skills. The purpose of this study was to use a battery of test scores to generate regression equations in order to predict training time and transfer performance in a pursuit tracking task. With these equations it might be possible to assign an individual to an optimal training condition based on his or her information processing characteristics.

METHOD

Subjects

Fifty-one male and 39 female undergraduate volunteers participated in the experiment. Subjects were right-handed, naive to the experimental task, and paid for their participation.

Tests

A pretest battery of six tests was given to each subject. The first test measured time-on-target across six, 30-s trials on a pursuit rotor moving at 60 revolutions per minute. The second test was the Embedded Figures Test (Watkin, Otman, Raskin, and Karp, 1971) which measures the perceptual ability of field independence and field dependence. The remaining four tests were chosen from a paper-and-pencil battery developed by Ekstrom, French, Harmon, and Dermen (1976) which was designed to measure various cognitive components related to information processing. These tests included: the Map Memory Test for a measure of visual memory; the Cube Comparison Test for a measure of spatial orientation; the Identical Pictures Test for a measure of perceptual speed; and the Maze Tracing Test for a measure of spatial scanning.

<u>Training Task and Procedures</u>

The training and transfer tasks used a Digital Equipment Corporation PDP 11/10 digital computer linked to a CRT display and a two-axis pressure control stick. The tracking task involved two random band-limited functions which determined the X-Y coordinates of the forcing function symbol ("X") on the display; the control output ("O") was generated from the isometric controller. Feedback bars were used to provide information on error and level of difficulty. The control system was an 80% acceleration system where the maximum gain output of the control stick was 50.8 cm/s. Task difficulty was manipulated in terms of maximum movement of the forcing function symbol. The criterion level of task difficulty during training was 20.3 cm/s. The error tolerance was 10% of the screen diagonal (18 cm by 18 cm).

Following completion of the six tests each subject learned a pursuit tracking task using one of three possible training approaches: fixed difficulty, shifting difficulty, or adaptive. The fixed difficulty condition is the traditional approach to motor skill training in which trainees are presented the criterion task initially and their error decreases as training progresses. A more individualized approach is the adaptive training condition which involves a set of decision rules to manipulate task difficulty in a closed-loop system (Kelly, 1969). Student performance is monitored and compared to a standard by adjusting the difficulty of the task so that the performance of the student is relatively stable throughout training. The shifting difficulty condition evolved from an earlier study (Williges and Williges, 1977) in which subjects controlled the level of task difficulty. Many subjects initially set the task difficulty at a low level and later shifted the difficulty to the criterion level. In the shifting difficulty condition, the level of difficulty during Trial 1 was at a low level (0.2 cm/s); in Trial 2 and all sequent trials, the task difficulty was at the criterion level.

<u>Transfer Task</u>

A 5-min rest occurred between the training and transfer tasks. The 7-min transfer task was similar to the training task except no performance information was provided. Three levels of task difficulty in terms of the maximum speed of the forcing function were presented. The three levels of difficulty were the exit criterion (20.3 cm/s), more difficult than the exit criterion (30.5 cm/s), and less difficult than the exit criterion (10.2 cm/s).

RESULTS AND DISCUSSION

Scores from the six tests were used to generate least squares regression equations for each of the three training conditions. Time-to-exit in training and mean performance during the first six minutes in transfer were used as dependent measures. Separate equations were also calculated for males and females in each training condition. The best regression equations resulting from five stepwise procedures were chosen which could account for the most variance with the least variables. Each of the resulting regression equations used standarized (Z) scores for the predictor pretest variables.

TABLE 1

The Multiple R^2, Estimate of Shrinkage, R_s^2, and Number of Subjects in Each Regression Equation.

	Adaptive			Fixed			Shift		
	R^2	R_s^2	N	R^2	R_s^2	N	R^2	R_s^2	N
Overall	.717	.673	31	.639	.610	28	.566	.518	31
Male	.750	.717	18	.803	.758	16	.614	.485	17
Female	.871	.806	13	.476	.364	12	.731	.650	14

Table 1 presents the multiple R^2, the estimate of shrinkage, R_s^2, (Kerlinger and Pedhazur, 1973), and the number of subjects for each equation in the three training conditions using time-to-exit as the dependent variable. Each of these regression equations was statistically significant ($p<.05$), and the shrinkage was minimal with the exception of the shift-male subjects and the fixed-female subjects. It is important to note that when the regression equations in Table 1 are broken down by sex, a larger proportion of variance can be accounted for with the only exception being the equation for the fixed-female subjects. This observation would seem to indicate that assigning subjects to an optimal training condition (based on predicted time-to-exit scores) should consider the sex of the subject.

Regression equations were also generated in the same manner using the mean transfer performance as the dependent variable. These equations were generally either unreliable or accounted for only a small proportion of the variance. The exceptions were the regression equations for the adaptive training condition which accounted for as much as 90% of the variance.

In determining which regression equations should be used to predict time-to-exit in each training condition in order to assign an individual to a optimal training strategy, it is apparent that the equations for the transfer task are too unreliable. On the other hand, the equations based on sex for predicting time-to-exit appear to be the most reliable. These six regression equations are presented in Table 2. It should be noted that across the various equations by sex and training condition, different sets of predictor variables are used in each equation, not just different weightings. This observation also argues for the need for regression equations based on the sex of the individual.

CONCLUSION

Although the results of this study demonstrate that it is possible to predict reliably training time-to-exit when individual differences due to the sex of the subject are considered, additional research needs to be

TABLE 2

Regression Equations for Training Time-to-Exit by Training Condition and Sex

---

<u>Adaptive/Male</u>

$$TE = 1069.50 + 509.86\ EF + (-325.06)\ MM$$

<u>Adaptive/Female</u>

$$TE = 1967.61 + (-492.83)\ MM + 391.02\ IP + (0358.42)\ CC + 196.43\ PR$$

<u>Fixed Difficulty/Male</u>

$$TE = 867.84 + 412.35\ IP + 333.12\ EF$$

<u>Fixed Difficulty/Female</u>

$$TE = 1551.25 + 467.82\ EF + 144.51\ MM$$

<u>Shifting Difficulty/Male</u>

$$TE = 857.38 + (-361.85)\ EF + (-354.74)\ CC + (-335.53)\ PR + (-177.03)\ MT$$

<u>Shifting Difficulty/Female</u>

$$TE = 1219.86 + (-266.34)\ PR + (-223.36)\ CC + (-199.44)\ MT$$

TE = Training Time-to-Exit
PR = Pursuit Rotor (continuous motor skill)
EF = Embedded Figures Test (field independence)
MM = Map Memory Test (visual memory)
IP = Identical Pictures Test (perceptual speed)
CC = Cube Comparison Test (spatial orientation)
MT = Maze Tracing Test (spatial scanning)

---

directed toward cross-validating these equations with a new sample of subjects. Future research is also needed to validate the potential use of these equations in placing individuals in an optimal training condition. This would involve matching subjects to an optimal training condition based on their predicted scores and comparing their training effectiveness to mismatched subjects. If the prediction equations can withstand this experimental scrutiny, then meaningful implications can be stated concerning the role of individual differences in choosing the most appropriate training strategy.

ACKNOWLEDGMENTS

Contractual support for this project was provided by the Life Sciences Program, Air Force Office of Scientific Research, Grant Number 77-3161. Captain Jack A. Thorpe served as the scientific monitor. The authors wish to thank John E. Evans for software support.

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Appendix D

Matching Initial Performance and the Measurement of Sex Differences

Proceedings of the Sixth Psychology in the DoD, April, 1978.

MATCHING INITIAL PERFORMANCE AND THE MEASUREMENT OF SEX DIFFERENCES

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Women are increasingly being selected to perform traditionally male jobs, including tasks requiring a high degree of motor skill. However, little data exist on female motor performance and the effects of training on the development of motor skills. Two studies that examined sex differences in a two-dimensional pursuit tracking task are presented. Results of these studies imply the need for a multifactor matching procedure to study sex differences in motor skills.

Increasingly the "man" in many man-machine systems is a woman. For example, women are being used in vehicular control systems requiring a high degree of motor skill. And, yet, little data exist on female motor skill performance and the effects of various training models on the development of motor skill. A recent survey by Hudgens and Billingsley (1978) analyzed the sex of subjects included in studies published in Human Factors and Ergonomics for the time period of 1965 through 1976. Their results indicate that only a quarter of the studies included females either exclusively (6%) or with males (19%). In addition, the percentage of studies that include women, reported in these two journals, has not increased in recent years. Human factors data on women are urgently needed in order to establish appropriate training programs for women and to redesign equipment and jobs for women, when necessary.

SEX DIFFERENCES IN MOTOR SKILLS

Evidence for differences in tracking skill favoring males has been obtained with children (Ammons, Alprin, and Ammons, 1955) and with college students (Noble, 1970). However, it is not safe to conclude that males and females, therefore, differ in motor abilities or learning rates. Singer (1975) suggests that these sex differences may be the result of transfer of non-specific training, previous experience with the task, motivational differences, and/or sociocultural factors such as a need for social approval.

Prior Experience

Williges and Williges (1977) reported the results of a study to examine sex differences in learning a two-dimensional pursuit tracking task using a fixed difficulty training model, an adaptive training model (Kelley, 1969), or a learner-centered model. They reported a highly reliable ($p<.001$) sex difference in training time-to-exit favoring males. However, no reliable differences in tracking error between males and females were found in transfer ($p = .48$) even during those periods during the transfer task when the level of tracking difficulty exceeded the maximum level of task difficulty during training. These results suggest that, although women may require some additional training time initially on motor-control tasks similar to the one used in this study, no performance differences by sex should be expected once training is accomplished.

Possibly many of the sex differences in motor skills are more correctly measures of prior experience with similar motor-control tasks. In the Williges and Williges (1977) study, an analysis of variance on vector error for the fixed difficulty training group in the first 3 min of training was conducted and revealed a reliable sex difference, $\underline{F}(1, 10)=9.45$, $\underline{p}<.05$. At least in the fixed-difficulty condition, males and females were not equated in terms of initial motor performance.

MATCHING PROCEDURES TO STUDY SEX DIFFERENCES

One disadvantage of a between-subjects design is that quite by accident subjects randomly assigned to one or more treatment group can have significantly different prior experience, skill, or motivation than subjects assigned to the remaining treatment groups. Another possibility is that of drawing from different populations in terms of initial skill level. When subjects are drawn from two distributions which overlap but have different means, the most likely result, given random sampling, is two samples with different means (unmatched).

However, in training situations a within-subject design is impossible because of the baseline problem. To make the subject population as uniform as possible, a common procedure is to match subjects on some concomitant variable that is correlated with the dependent variable. Usually a matching variable is selected based either upon previous documentation of its appropriateness or preliminary experimentation.

Selecting a Matching Variable

To minimize initial performance differences between males and females, the present authors chose to match male and female subjects for a second study of sex differences in pursuit tracking. In order to select an appropriate matching variable, a pretest was conducted using four simple motor tasks: pursuit rotor tracking, a one-dimensional (y-axis) pursuit tracking task, a one-dimensional (x-axis) compensatory tracking task in which task difficulty increased over time, and a television game (handball) in which the object was to maximize time in the game. Ten male subjects were pretested, and then four received fixed-difficulty training and six received adaptive training. Table 1 summarizes the Pearson Product Moment Correlations of each pretest with training time-to-exit and with transfer tracking error. The only pretest which resulted in a consistently high correlation across the two training conditions was the rotary pursuit.

Subsequently, 90 subjects were tested with the pursuit rotor in order that 30 male and 30 female subjects could be matched and assigned to three training conditions. Table 2 provides means and standard deviations by sex for the original random sample of subjects and for the matched sample. Obviously, matching did reduce the performance differences by sex on the pursuit rotor task. Methodological details of this study are given in Williges, Williges, and Savage (1977). Of importance here is the adequacy of the matching procedure employed. Table 3 provides a comparison of Pearson Product Moment Correlations in the preliminary and main studies for training and transfer. In general the correlations of pursuit rotor scores with training time dropped in the main study particularly for females in the adaptive training condition. Obviously, a serious flaw in the preliminary

study was the failure to use any female subjects. However, even for male subjects the correlations dropped substantially, perhaps to the point of rendering the pursuit rotor scores useless as a matching variable. It becomes apparent that matching male and female students on initial motor skill performance is not an easy task. What procedure, then, can be used?

TABLE 1

Pearson Product Moment Correlations of Pretest Tasks with Training Time-to-Exit and with Transfer Tracking Error

	Pretest			
Training Condition	PR	PT	CT	TV
Training Time-to-Exit				
Adaptive	-.762	-.292	.164	-.249
Fixed	-.711	.886	-.496	.352
Overall	-.550	.147	-.138	-.065
Transfer Tracking Accuracy				
Adaptive	-.471	-.365	.051	-.642
Fixed	-.608	.633	-.827	.422
Overall	-.425	.106	-.447	-.340

PR = pursuit rotor tracking
PT = y-axis pursuit tracking
CT = x-axis compensatory tracking
TV = television game

TABLE 2

Means and Standard Deviations of Pursuit Rotor Scores by Sex for Random and Matched Samples of Subjects

Sex	Random Sample			Matched Sample		
	N	$\bar{X}$	σ	N	$\bar{X}$	σ
Male	51	8.92	4.90	30	6.14	2.79
Female	39	4.95	2.99	30	5.61	2.92

Multi-Factor Matching

As part of the pretest package five tests in addition to the pursuit rotor were administered. These tests were various measures of information processing capacity of the student and are described in more detail by Savage, Williges, and Williges (1978). Standardized scores from all six tests were used to generate least squares regression equations for each sex and training condition combination. See Table 2 for the multiple R^2, estimate of shrinkage, R^2_s (Kerlinger and Pedhazur, 1973), and number of subjects in each sex/training

TABLE 3

Pearson Product Moment Correlations of Pursuit Rotor Scores, Multiple R^2, Estimate of Shrinkage (R_s^2), and Number of Subjects for Training and Transfer

	Preliminary Study		Main Study			
	N	r	N	r	R^2	R_s^2
Training Time-to-Exit						
Adaptive Training						
Male	6	-.762	18	-.600	.750	.717
Female	*	*	13	-.319	.871	.806
Fixed Training						
Male	4	-.711	16	-.446	.803	.758
Female	*	*	12	-.454	.476	.364
Transfer Tracking Error						
Adaptive Training						
Male	6	-.471	18	-.215	.545	.484
Female	*	*	13	-.193	.906	.875
Fixed Training						
Male	4	-.608	16	-.307	**	**
Female	*	*	12	-.690	.807	.697

* No females in the preliminary study.
** No reliable regression equation.

condition combination. For estimating training time-to-exit a substantial improvement was obtained using a multi-factor predictor. For estimating transfer tracking error, the multi-factor predictor was useful only for females.

Practice and Task-Specific versus General Abilities

Various researchers (Adams, 1957; Fleishman, 1960; Jones, 1972) have noted that in complex tasks initial task performance is often related to general abilities. As training proceeds, however, task-specific variables become more important predictors.

In the test battery administered, all the tests besides the pursuit rotor measure cognitive/perceptual (general) abilities. One could speculate that the diminished ability of the test battery to predict transfer performance for males reflects a movement to a more advanced stage of training where task-specific variables have more importance as predictors.

IMPLICATIONS

It is obvious that a data base on female performance is essential to facilitate the incorporation of women into traditionally all-male systems. However, acquiring a useful data base on women is not a simple task. Results of the two studies presented in this paper imply a need for a more sophisticated multi-factor procedures for matching subjects to study sex differences in motor skills.

ACKNOWLEDGMENTS

Contractual support for this project was provided by the Life Sciences Program, Air Force Office of Scientific Research, Grant Number 77-3161. Captain Jack A. Thorpe served as the scientific monitor.

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Appendix E

Augmented Feedback in Adaptive
Motor Skill Training

AUGMENTED FEEDBACK IN ADAPTIVE MOTOR SKILL TRAINING

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Two training models in motor learning and the effects of visually presented augmented feedback on training and transfer were examined in two studies using a two-dimensional pursuit tracking task. Training in both studies consisted of 3-min trials and continued until criterion performance was attained. The transfer task used in both studies consisted of one 7-min session in which tracking difficulty shifted each minute. In Study I, the combined effects of training type and augmented feedback on training time and transfer performance were examined. Twenty-four male college students were randomly assigned to one of four training conditions. These were: (1) fixed-difficulty with no augmented feedback, (2) fixed-difficulty with augmented feedback, (3) automatic adaptive with no augmented feedback, and (4) automatic adaptive with augmented feedback. In transfer, no feedback was given in all groups. No differences in training time were observed. However, subjects trained using the automatic adaptive model exhibited significantly less tracking error in transfer. In Study II, four automatic adaptive training conditions were used to examine possible interactions between the automatic adaptive training model and feedback cues in training and transfer. Six male college students were randomly assigned to each condition. Feedback in the four conditions was: (1) training-no feedback, transfer-no feedback, (2) training-feedback, transfer-no feedback, (3) training-no feedback, transfer-feedback, and (4) training-feedback, transfer-feedback. No reliable differences due to feedback occurred in training or transfer. The lack of reliable differences due to feedback in both studies is believed to be a result of an overload of the visual channel.

INTRODUCTION

The effects of augmented feedback in traditional motor skills training have received considerable attention. However, little research has been carried out on the effects of augmented feedback in closed-loop motor skills training systems such as adaptive training. In an adaptive training system, one or more variables important to a specific task are changed according to the trainee's performance. As the trainee's performance improves, the difficulty level of the "adaptive" variable(s) is manipulated such that performance error on the "adapting" variable(s) remains relatively constant throughout training. Adaptive procedures eliminate much of the intrinsic feedback in any task since the trainee does not readily see performance improvement because error remains relatively constant. Kelly (1969), in proposing an adaptive training technique, suggested (but did not experimentally test) that feedback indicating the level of difficulty of the training task needs to be provided to the trainee in adaptive training systems. Norman (1973) provided subjects in an adaptive flight training system with visually augmented level of difficulty feedback and found the feedback to have no effect on training performance. However, when feedback was withdrawn in transfer, subjects who received feedback in training performed significantly better than those who were in the no feedback training groups. Unfortunately, the reliability of these findings is questioned since they are based on the results of more than one experiment in which different subject pools were used, the independent variables varied, and the training task was substantially different from the transfer task.

Research on augmented feedback in traditional motor skills training has yielded conflicting results. Archer, Kent and Mote (1956), Archer and Namikas (1958), and Bilodeau and Rosenquist (1964) found augmented feedback to have no effect on subjects' performance in training or transfer. Numerous other studies have found augmented feedback to aid performance in training but to have no effect on transfer performance when feedback is withdrawn (Morin and Gagne, 1951; Bilodeau, 1952; Goldstein and Rittenhouse, 1954; Bilodeau, 1955; Payne and Hauty, 1955; and Karlin and Mortimer, 1963). Other researchers have found that augmented feedback produces a learning effect where the performance of the feedback groups remains significantly better than that of the no feedback groups even after the augmented feedback is withdrawn (Reynolds and Adams, 1953; Smode, 1958; Williams and Briggs, 1962; Kinkade, 1963; Karlin, 1965; Gordon and Gottlieb, 1967; and Gordon, 1968).

Several conclusions regarding the use of augmented feedback in traditional motor skills training have come from this research to account for these conflicting results. Welford (1968) observed that supplemental feedback must not provide cues which are eventually relied upon to the extent that when the feedback is withdrawn the trainee is no longer able to maintain adequate performance. Clarity of the intrinsic feedback provided by the training task has also been found to be an important variable interacting with augmented feedback (Kinkade, 1963). If the intrinsic feedback in the training system is not clearly discernible, the additional

feedback provided will become a part of the total information used to guide performance. Thus, the function of the augmented feedback will change from its intended purpose of aiding in the evaluation of performance to one of guiding performance.

Williams and Briggs (1962) concluded that the type of behavior indicated by the augmented feedback is related to the effect it produces. With feedback indicating out-of-tolerance performance, large errors are emphasized early in training and the trainee learns to minimize them quickly. With feedback indicating in-tolerance performance, small errors are emphasized and the trainee is not as quick in responding to correct large errors not emphasized by the feedback. Finally, Bilodeau (1966) and Annett (1969) suggest that the augmented feedback should direct the attention of the trainees to the results of their responses and thus their errors.

The conclusions reached for traditional motor skills training cannot be generalized to closed-loop forms of motor skills training without empirical testing. The purpose of this research was to evaluate the effects of visually presented augmented feedback on motor skills learning using either traditional, open-loop training or closed-loop training. Two studies were conducted using a two-dimensional pursuit tracking task. Feedback in both studies was in terms of task difficulty and performance accuracy (see Figure 1). The training procedures used were: (1) a fixed-difficulty procedure representing traditional motor skills training in which the trainees were presented with the criterion task immediately and their performance error decreased as training progressed, and (2) an automatic adaptive training procedure in which task difficulty increased gradually to criterion task difficulty as a function of the trainee's performance such that tracking error remained relatively constant throughout training.

STUDY I: EFFECTS OF FEEDBACK IN FIXED VERSUS ADAPTIVE TRAINING

To investigate the combined effects of visually presented augmented feedback and training procedure, a study was conducted in which subjects were trained in one of four ways. These were: (1) a fixed-difficulty procedure in which no augmented feedback was presented, (2) a fixed-difficulty procedure in which visual augmented feedback was presented, (3) an automatic adaptive procedure in which no augmented feedback was presented, and (4) an automatic adaptive procedure in which visual augmented feedback was presented. A transfer task similar to the training task was given to all groups in which feedback was not presented.

Method

Equipment. The equipment interfaces involved a Digital Equipment Corporation PDP 11/10 digital computer linked directly to a Tektronix

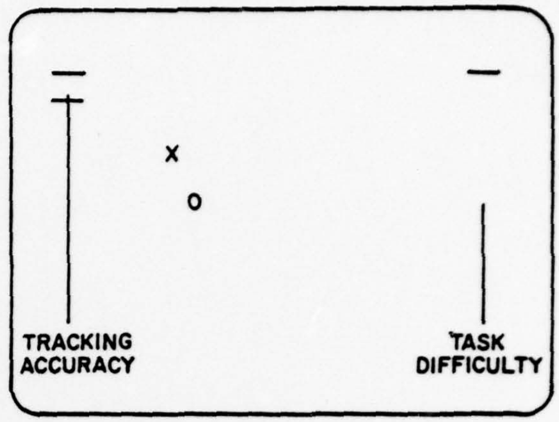

Figure 1. Two-dimensional pursuit tracking task.

4010-1 computer display terminal and a Measurement Systems Model 435 two-axis isometric control stick. The software program involved two independent real-time cycles--a 60-Hz refresh cycle and a 60-ms cycle to update the task and the augmented feedback.

Training task. Trainees learned a two-dimensional pursuit tracking task in which two random, band-limited functions were used to determine the x-y coordinates of the forcing function symbol ("X") on the display. Control output, symbolized by an "O" on the display, was generated using inputs from the isometric controller.

The effective tracking area on the Tektronix phosphorous display was 12.7 cm X 12.7 cm with the feedback bars appearing outside of this area. Subjects rested their head on a forehead rest such that viewing distance was kept constant at one meter. With this viewing distance, the feedback bars were well within central vision. The tracking symbols presented on the display occupied a 0.64 cm X 0.48 cm area.

The control system dynamics were neither pure rate nor pure acceleration. For each stick output, the corresponding positions of the "O" under both pure rate and pure acceleration control were calculated. The following formula was used to determine the actual new position of the "O":

$$\Theta_0 = (1-\alpha)\frac{K}{S} + \alpha\frac{K}{S^2} \qquad (1)$$

where Θ_0 equals the order of the control system, K is the gain constant, S is the Laplace transform, and α is the percentage of acceleration control. In both studies, α was 0.80. The gain output of the control stick at maximum pressure did not exceed 40.64 cm/s.

The forcing function symbol was manipulated by simulating a computer-operated control stick. Task difficulty, in terms of the movement speed of the forcing function symbol, was changed relative to the gain output of the simulated control stick. The criterion level of task difficulty during training was a maximum possible movement speed of the "X" of 20.32 cm/s. A small-step adaptive logic was used to manipulate the forcing function frequency. Absolute vector tracking error was computed every 60 ms for both training procedures and, in the adaptive procedure, was compared to a tolerance limit of 10% of the screen diagonal. A total of 1851 task difficulty steps requiring a minimum time of 111.1 s to reach the exit criterion level of difficulty was used. In the fixed-difficulty training procedure, the speed of the "X" was maintained at the criterion level throughout training. Exit criterion training performance in all conditions was the maintenance of the "O" within 10% of the screen diagonal of the "X" for a period of 20 continuous seconds while the "X" was moving at the criterion level of difficulty. In order to avoid confounding fatigue effects, subjects were given a maximum of fifteen 3-min trials spaced with 1-min rest periods to exit the training task.

Transfer task. After training to criterion and a 5-min rest period, each subject was given a 7-min transfer task similar to the training task with the exception that no feedback was given to any of the groups. Task difficulty shifted among three levels of difficulty after each minute of transfer. These three levels of difficulty were: the exit criterion forcing function level in training (20.32 cm/s), 0.5 X exit criterion level (10.16 cm/s), and 1.5 X exit criterion level (30.48 cm/s). The ordering of these difficulty levels was the same for each subject.

Subjects. Twenty-four paid volunteer male college students ranging in age from 18-29 years were randomly assigned to one of the four training conditions. All were right-handed and naive to the experimental task. Before participating in the study, all subjects were given a full vision test with a Bausch and Lomb Orthorater and were required to have at least 20/25 vision (near and far, corrected or uncorrected). Only male subjects were used to eliminate any sex differences that may exist in motor skills training (Williges, Williges, and Savage, 1977).

Results

Three subjects failed to exit from the training task in the allotted fifteen trials. Two were in the adaptive training without augmented feedback condition and the other was in the fixed-difficulty without augmented feedback condition. Thus, a total of twenty-seven subjects were required to balance the four training conditions with six subjects each. All subjects were presented the transfer task, whether or not they exited from training within the allotted fifteen trials. The results presented in this paper are based on an equal n's analysis of variance of the subjects who exited from training. However, an unequal n's analysis of variance was performed on the data, and any discrepancies in this analysis from the equal n's analysis are noted.

Training. A two-factor analysis of variance of time-to-exit scores yielded no significant differences in training time due to either training procedure or augmented feedback ($p > 0.10$). The mean time-to-exit was 24.1 min, 23.7 min, 17.7 min, and 17.7 min for the adaptive feedback, fixed-difficulty no-feedback, adaptive no-feedback, and fixed-difficulty feedback conditions, respectively.

Transfer. An analysis of variance on vector RMS error integrated over each minute of the transfer task was conducted with training procedure, feedback in training, level of difficulty during transfer, and time of occurrence of the level of difficulty during transfer as factors.

The main effect of level of difficulty was significant, $F(2,40) = 285.40$, $p < 0.0001$, indicating that the three levels presented in transfer did represent different skill levels. Tracking error increased with greater task difficulty (10.5%, 15.9% and 22.5% respectively).

A more important result from the analysis of variance was the finding that training procedure had a significant effect upon transfer performance, $F(1,20) = 9.24$, $p < .0065$. The mean vector error for those trained adaptively was 12.4%, whereas the mean vector error of those trained in the fixed-difficulty conditions was 14.1%. However, this main effect was not reliable when the three subjects who failed to exit from the training task were included in the analysis. No interactions were significant ($p > 0.10$).

Discussion

Time-to-exit scores among the four training conditions were not significantly different. Thus, visually presented augmented feedback did not aid subjects in either type of training procedure. Furthermore, subjects trained adaptively required the same amount of training as those in the fixed-difficulty conditions. However, subjects who were trained adaptively and exited from training performed with significantly less vector RMS error in transfer than subjects trained in the fixed-difficulty conditions. The presence of feedback in training did not prove to have any effect on transfer performance.

STUDY II: ADAPTIVE TRAINING AND THE PRESENTATION OF AUGMENTED FEEDBACK IN TRAINING AND TRANSFER

In Study I, the point of interest was the relative effect of augmented feedback cues on automatic adaptive motor skill training. However, no feedback cues were presented in transfer. The purpose of Study II was to assess

whether augmented feedback resulted in either learning or performance effects. Four automatic adaptive conditions were used to accomplish this. The conditions were as follows: (1) training and transfer without feedback, (2) training with feedback, transfer without feedback, (3) training without feedback, transfer with feedback, and (4) training and transfer with feedback.

Method

Equipment and training task. Same as in Study I.

Transfer task. Same as in Study I with the exception that some subjects did receive feedback in transfer according to the conditions in the experimental design.

Subjects. Twenty-four paid volunteer male college students ranging in age from 18-26 years were randomly assigned to one of the four experimental conditions. All other subject qualifications were identical to those in Study I.

Results

Five subjects failed to exit the training task in the allotted fifteen trials. Two were in the training and transfer without feedback group, one was in the training and transfer with feedback group, and two were in the training without feedback-transfer with feedback group. Thus, a total of twenty-nine subjects were required to balance the four conditions with six subjects each. All subjects were presented the transfer task whether or not they exited from training within the allotted fifteen trials. An equal n's analysis of variance and an unequal n's analysis of variance were performed on the data. No discrepancies of significance were obtained with these two analysis.

Training. A one-way analysis of variance of time-to-exit scores yielded no reliable effect of augmented feedback on training time-to-exit (p>0.10). The mean time-to-exit score for the groups that received feedback in training (Groups 1 and 2) was 22.4 min with a standard deviation of 9.9 min while the mean time-to-exit score for the groups that did not receive feedback in training (Groups 3 and 4) was 18.5 min with a standard deviation of 9.0 min.

Transfer. An analysis of variance on vector RMS error integrated over each minute of the transfer task was conducted with feedback in training, feedback in transfer, level of task difficulty during transfer, and time of occurrence of the level of difficulty during transfer as factors.

The main effect of level of difficulty was once again significant, $F(2,40)=214.53$, $p<0.0001$, indicating that the three levels presented in transfer did represent different skill levels. Tracking error increased with greater task difficulty (9.3%, 14.2% and 17.4%, respectively). The main effects as well as interactions of feedback in training and transfer were not significant (p>0.10).

Discussion

As in Study I, feedback in training had no significant effect on training time. Even though there was no overall reliable difference between feedback and no-feedback training conditions, several subjects commented that when they attempted to use the augmented feedback, their tracking performance declined sharply. In transfer, no significant effects due to feedback in training and/or transfer were observed (p>0.10). Consequently, these data provide no support for a learning effect due to visually presented feedback.

CONCLUSION

Based on the findings of these two studies, one can conclude that visually presented augmented feedback in the form of bar graphs in a two-dimensional pursuit tracking task does not aid tracking performance in training nor transfer. However, it appears that the motor skill task used in these studies was too complex to permit the subjects to use the feedback cues provided. More research needs to be conducted using complex motor tasks and other forms of augmented feedback that appeal to different sensory modalities to determine if augmented feedback enhances adaptive motor skills training.

ACKNOWLEDGMENTS

Contractual support for this paper was provided by the Life Sciences Program, Air Force Office of Scientific Research, Grant Number 77-3161A. Captain Jack A. Thorpe was the scientific monitor for the grant. John E. Evans provided software support for the research. Ricky E. Savage aided in the analyses of the data.

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Appendix F

Cross-Validation of Regression Equations to Predict Performance in a Pursuit Tracking Task

CROSS-VALIDATION OF REGRESSION EQUATIONS TO PREDICT PERFORMANCE IN A PURSUIT TRACKING TASK

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A double, cross-validation procedure was used to validate regression equations which predict training time to learn a two-dimensional pursuit tracking task. Motor skill and information processing tasks were used as predictors. The results yielded a reliable regression equation for each training condition, and these equations were quite similar in cross-validation. Subsequently, a regression equation based on pooled data from the original and cross-validation sample was calculated for each training condition. To establish the usefulness of a regression approach for selecting training strategies, these equations will be used in a future study where students will be matched, mismatched, and randomly assigned to various training alternatives.

INTRODUCTION

Adaptive training techniques optimize training by individually adjusting task difficulty for a wide range of skill levels. Adaptive training involves a closed-loop logic system in which the level of student performance determines the level of task difficulty. The usual approach taken in adaptive procedures is to use only one logic system with the implicit assumption that there is one optimum logic for all individuals. Even though this one logic system provides a variety of individual task difficulty profiles, it may not provide enough flexibility for different learning strategies.

Research is needed to determine the specific dimensions of individual differences that are associated with various training alternatives, the methods for improving the definition and measurement of learner characteristics, and the matching rules that can be used to select the optimal instructional strategy for various characteristic profiles. Work by Pask (1976) on cognitive tasks indicates that the matching of the instructional strategy and individual characteristics is a critical factor in maximizing training. Pask's research points out that when the student's preferred learning style and teaching strategy are mismatched, learning is severely disrupted in terms of comprehension and retention.

Recent interest in the relationship between information processing skills and motor skills may have implications for investigating individual differences in motor learning. Marteniuk (1976) has suggested that limitations in information processing capabilities can limit motor performance. If these perceptual or cognitive processes can be measured, differences in information processing skills as they relate to motor skills can be studied. The purpose of this research was to use a battery of tests to generate and cross-validate regression equations predicting training time-to-exit from a pursuit tracking task. With these equations it might be possible to assign an individual to an optimal training condition based upon information processing characteristics. Two studies are reported - one to generate regression equations and one to cross-validate these equations.

STUDY I

Method

Subjects. Thirty-three male and 26 female university students volunteered to participate in the experiment. The subjects were right-handed, naive to the experiment, and paid for their participation.

Pre-test battery. A battery of six tests was used to provide predictor variables. The tests included: (1) Pursuit Rotor (motor skill); (2) Embedded Figures Test (field independence); (3) Indentical Pictures Test (perceptual speed); (4) Maze Tracing Test (spatial scanning); (5) Map Memory Test (visual memory); and (6) Cube Comparison Test (spatial orientation). The Embedded Figures Test is from the Educational Testing Service (Witkin, Oltman, Raskin, and Karp, 1971), and the last four tests are paper-and-pencil tests from the Ekstrom, French, Harman, and Derman (1976) battery.

Procedure. After completing the pretest battery, students were randomly assigned to one of two training conditions. In fixed difficulty training, students were immediately presented with the criterion task and their error decreased as training progressed. In the adaptive training condition student tracking error was monitored and a logic system was used to adjust task difficulty.

The training and transfer tasks were generated by a PDP 11/10 digital computer which provided inputs to a Tektronix 4014-1 cathode ray tube display and processed control outputs from an isometric control stick. Each subject completed a series of 3-min tracking trials to learn a two-dimensional pursuit tracking task in which

TABLE 1

Coefficients of Multiple Determination (R^2), Estimate of Shrinkage (R_s^2), and Number of Subjects (n) for First-Order Regression Equations

Subjects	Adaptive n	Adaptive R^2	Adaptive R_s^2	Fixed Difficulty n	Fixed Difficulty R^2	Fixed Difficulty R_s^2
Overall	31	.721	.690	28	.639	.610
Male	18	.750	.717	16	.803	.758
Female	13	.817	.756	12	.431	.374

two-random, band-limited functions were used to determine the x-y coordinates of the forcing function symbol "X" on the display. The control output "O" was generated using inputs from the analog controller. Dynamic, augmented performance feedback was presented in addition to the forcing function and controller symbols used in the pursuit tracking task. One feedback bar depicted the current level of task difficulty in relation to the exit criterion level of difficulty. Task difficulty was defined by the maximum possible movement of the forcing function symbol. The other feedback bar showed a smoothed measure of current tracking accuracy in relation to both the acceptable level of accuracy required by the adaptive logic and perfect performance. In the adaptive training condition task difficulty increased when the vertical line depicting tracking accuracy was within the tolerance allowed. Conversely, the task difficulty decreased when tracking accuracy was out of tolerance. This procedure continued until the subject was able to perform the pursuit tracking task while maintaining both feedback bars at or above the exit criterion lines continuously for a specified period of time. In the fixed difficulty training condition, task difficulty was at the criterion level throughout training. Following a short rest period, each subject completed a transfer task which was a 7-min tracking session similar to the training task except that no augmented feedback information was provided. During transfer the level of difficulty of the task changed automatically after each minute of tracking. Three levels of difficulty were used: the same as the exit criterion in training, more difficult than the exit criterion, and less difficult than the exit criterion.

Results

Standardized scores from the six pretests were used to generate least squares regression equations to predict training time-to-exit. Five stepwise regression procedures were used, and the equations that accounted for the most variance with the least predictors were selected.

Table 1 presents the coefficient of multiple determination, R^2, the estimate of shrinkage (Kerlinger and Pedhazur, 1973), R_s^2, and the number of subjects, n, for each regression equation generated in Study I. Separate equations for male and female subjects as well as overall equations were generated for the adaptive and fixed difficulty training conditions.

All of the equations were reliable at the .05 level of significance and accounted for at least 43% of the variance in training time. In general the separate equations generated for male and female subjects accounted for more variance than the overall equations. In the overall equations, sex was used as an additional predictor but was a significant predictor only for adaptive training. These results demonstrated that it is possible to predict time-to-exit using a regression approach and information processing factors as predictors.

STUDY II

Method

In Study II cross-validation data were obtained by replicating the original design. Ten male and female subjects were used in each training condition for a total of 40 subjects in the new sample. Subject requirements, pretest battery, and training and transfer tasks were identical to Study I.

Results

A double cross-validation procedure was employed where the original equations were used to predict time-to-exit for the new sample (R_{12}^2), and new regression equations were generated from the new sample and used to predict time-to-exit for the original sample (R_{21}^2). For both samples correlations were calculated between the predicted and actual scores (R_{11}^2 and R_{22}^2). The coefficients of multiple determination are summarized in Table 2.

TABLE 2

Coefficients of Multiple Determination from Cross-Validation (Original R^2, Shrunken R^2, and Cross-Validation R^2)

Coefficient of Determination	Overall	Male	Female
	Adaptive Training		
R^2_{11}	.721	.750	.817
$R^2_{s_1}$	.690	.717	.756
R^2_{12}	.832	.619	.306
R^2_{22}	.859	.841	.827
$R^2_{s_2}$	.833	.796	.741
R^2_{21}	.699	.578	.511
	Fixed Difficulty Training		
R^2_{11}	.639	.803	.431
$R^2_{s_1}$	.610	.758	.374
R^2_{12}	.444	.178	.482
R^2_{22}	.611	.474	.905
$R^2_{s_2}$	.538	.324	.856
R^2_{21}	.472	.333	.003

Reduction or shrinkage was expected in the cross-validated correlations as compared to the original correlations due to the new samples of subjects and new testing time. When the original equations were used to predict time-to-exit for the new sample, the cross-validated coefficients of determination (R^2_{12}) were similar to the estimates of shrinkage (Kerlinger and Pedhauzer, 1973) ($R^2_{s_1}$) except for the equations developed for females using adaptive training and males using fixed difficulty training. When the new equations were used to predict time-to-exit for the original samples, the cross-validated coefficients of determination (R^2_{21}) were similar to the estimates of shrinkage ($R^2_{s_2}$) except for the equation developed for females using fixed difficulty training. It should be noted that although the actual shrinkage of the equation developed for males using fixed difficulty training did not exceed the estimated shrinkage, the coefficient of determination was relatively low.

The coefficients of determination were consistently high for the overall equations. In addition, the significant predictors in the equations derived from the original and new samples were consistent. The only difference was the addition of one new variable in the fixed training equation. However, the original variables were also significant and were more heavily weighted than the new variable. Therefore, the data from the two samples were combined, and new overall equations were generated as shown in Table 3. Each of these equations is reliable at the .0001 level of significance. These appear to be the best equations to predict training time. Although the Embedded Figures Test is the dominant predictor in both equations, all other factors differ. Sex is a reliable predictor only for adaptive training. These differences in the equations should be sufficient to discriminate between the two training conditions in order to assign students to an optimal training condition based on individual characteristics.

TABLE 3

Combined Sample Regression Equations for Training Time-to-Exit

<u>Adaptive</u>

$$TE = 1326.85 + 381.82\ EF - 307.48\ MM + 259.52\ SE$$

$n = 51$

$R^2 = .756$

$R^2_s = .740$

$p \leq .0001$

<u>Fixed Difficulty</u>

$$TE = 994.57 + 405.77\ EF + 251.3\ IP - 139.28\ CC$$

$n = 48$

$R^2 = .632$

$R^2_s = .607$

$p \leq .0001$

CC = Cube Comparison Test

EF = Embedded Figures Test

IP = Identical Pictures Test

MM = Map Memory Test

SE = Sex

CONCLUSION

Based on the promising results of this research, various candidate measures of individual differences in information processing have been identified and need to be evaluated in future research. Specifically, scores from these tests will be used in the regression equations to determine assignments to various training alternatives. To establish the usefulness of regression equations for selecting training strategies, subjects will be matched, mismatched, or randomly assigned to various training alternatives, and training time-to-exit and transfer tracking error will be measured.

ACKNOWLEDGMENTS

Support for this research was provided by the Life Sciences Directorate, Air Force Office of Scientific Research, Grant Number 77-3161A. Captain Jack A. Thorpe served as the scientific technical monitor. John E. Evans, III provided software support for this project.

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Appendix G

Computer-Augmented Motor Skills Training

Proceedings of the International Conference on Cybernetics and Society, Tokyo-Kyoto, Japan, November 3-7, 1978.

COMPUTER-AUGMENTED MOTOR SKILLS TRAINING

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ABSTRACT

The development of efficient training strategies which allow for individual differences is essential to optimize training for complex motor skills. Three computer-augmented approaches to individualized motor skills training are discussed: adaptive training, learner-centered training, and matching learner characteristics with training alternatives. Data in these areas are reviewed, and critical research issues are specified.

1. INTRODUCTION

The training of complex motor skills particularly in aviation is an expensive process. Because of the high cost of training using actual equipment, more extensive use is being made of computer-controlled simulators. However, obtaining maximum transfer from a simulator may be as much a function of the way the simulator is used for training as it is a function of the degree and fidelity of simulation. The specification of efficient training strategies is essential to realize the full potential of computer-based training.

Traditionally motor skills training involves a fixed difficulty strategy in which students are immediately presented the criterion task and their error decreases as training progresses. Unfortunately this strategy has no provision for individual differences in prior experience and rate of learning. Therefore, the training task may be too easy at times for some individuals and too difficult at time for others, an inefficient use of training time. The need to allow for individual differences in motor skills training is obvious, and through the use of modern computer technology a variety of computer-controlled training procedures for motor skills is possible. In this paper three approaches to individualized motor skill training will be examined: adaptive training, learner-centered training, and matching student learning styles with training alternatives.

2. ADAPTIVE TRAINING

The use of the term adaptive training often refers to a motor learning task in which the difficulty or complexity of the training task varies directl as a function of student performance. If a student's performance is within a specific error tolerance, the task difficulty or complexity increases until the exit criterion is reached. If, the other hand, the trainee is outside a specifie error tolerance, the task difficulty is decreased With the adaptive model one assumes that the task is never too easy or too difficult for the studen much like the training provided by a skilled instructor. According to Kelley [1], an adaptive training system requires a continuous measure of student performance, one or more adaptive variabl that can change the task difficulty or complexity, and a logic system for automatically changing the adaptive variable(s). The adaptive training model optimizes training by individually adjusting task difficulty to provide for a wide range of skills.

Several preliminary applications of adaptive training to complex synthetic flight trainers have been attempted [2, 3, 4]. However, not all resea supports the superiority of adaptive training for motor skills, and it is these conflicts which poi toward areas in which research is needed to optim adaptive motor skills training. Williges and Williges [5] have summarized some of these critica research issues as they relate to performance measurement, adaptive variables, and adaptive logi

2.1 Performance measurement

Many factors are important in performance measurement in adaptive training. Research by Gopher, Williges, Williges, and Damos [6] has demonstrated dimension differences in rate of learni a multi-dimensional tracking task. But, few data exist to determine whether multiple dimensions should be measured separately or simultaneously f optimal adaptive training; and if simultaneous measurements are used, which combining procedures are best. A related issue involves the need to de velop multivariate procedures to calculate composi performance scores in complex environments where multiple measures are required [7]. And, finally, even the duration of the performance measurement interval can affect training [8,9]. Research is needed to determine the optimal measurement inter for various types of motor learning tasks.

2.2 Adaptive variables

Many different variables have been used as th adaptive variable. However, research by Gopher,

*Research support for this paper was provided by the Life Sciences Program, Air Force Office of Scientific Research, Grant Number 77-3161. Captain Jack A. Thorpe served as the scientific monitor.

et al. [6] indicated that response variables, such as the ratio of acceleration to velocity control, inhibit learning; whereas stimulus variables, such as frequency or amplitude of the forcing function, promote learning. One can postulate that the need to change response strategies to the same stimuli results in an inhibition paradigm which negates any advantage of adaptive training. These data need to be extended to additional stimulus variables, and the effect of adapting single versus multiple stimulus-related variables needs to be explored.

2.3 Adaptive logic

The central element in an adaptive system is the specification of the adaptive logic. Crooks and Roscoe [10] investigated the effects of manipulating error limits during adaptive training. Lintern and Gopher [11] have proposed that the adaptive logic rules themselves might need to change as training progresses. However, additional data are needed before any definitive conclusions can be reached on these matters.

Several investigators have studied the need for augmented feedback in adaptive training and have obtained conflicting results [8, 12]. Recent research [13] yielded positive results by adaptively manipulating the presence or absence of augmented feedback during training. Issues, such as the information to be provided as augmented feedback, the communication mode for augmented feedback, and the withdrawal of augmented feedback, need to be addressed.

Most adaptive logic schemes are not based on existing human learning models. Chatfield and Gidcomb [14] suggested that Markovian models might be used to formalize the logic in higher-order adaptive systems which are tailored to individual differences. These models can be used to describe the student's performance so that the adaptive logic can select strategies on the basis of hypothesized learning states of the individual.

But, the usual approach taken in adaptive procedures is to use only one logic system for all individuals with the implicit assumption that there is one optimum logic for everyone. Even though this one logic system will provide a variety of individual task difficulty profiles, it may not provide enough flexibility.

3. LEARNER-CENTERED INSTRUCTION

The antithesis of the adaptive model is learner-centered instruction in which the lesson strategy is controlled by the student directly. The learner-centered model has two primary advantages. First, learner-centered instruction is economical to develop because elaborate software programs for selecting content or sequence are unnecessary. Second, students using learner-centered instruction learn to evaluate their own performance and thereby develop their own internal feedback mechanism. The most straightforward way to implement the learner-centered approach is to make the motor skills task manually adaptive by providing a switch which allows the students to increase or decrease the level of difficulty as they wish. Students, thereby, provide their own training strategy as compared to one computerized logic scheme present in an automatically adaptive training situation.

Research on learner-centered instruction for cognitive skills provides some support for the approach [15, 16, 17]. Learner-centered instruction resulted in an improved student attitude toward training and in some cases reduced training time.

Williges and Williges [18] conducted the first research on learner-centered instruction in motor learning. Students used either fixed difficulty, adaptive, or learner-centered strategies to learn a two-dimensional pursuit tracking task. No reliable differences in training time were noted, but students trained using learner-centered procedures had less tracking error ($p < .05$) in the 7-minute transfer task. These results indicate that the student is quite capable of effectively manipulating the learning situation based on his own internal training model.

One could argue that learner-centered instruction fared so well only because the computer learning algorithm used was unsophisticated and, therefore, was suboptimal for the task to be learned. However, until more sophisticated logic schemes are developed and evaluated, the training designer might be well-advised to consider a learner-centered approach to individualize motor skills training.

One disadvantage of the learner-centered model is that the complexity of the students' decisions increases as the complexity of the training situation increases. For example, in the Williges and Williges study [15], students had only three possible inputs--increase task difficulty, decrease task difficulty, or keep task difficulty the same. If the difficulty of each axis in the task were manipulated separately, the students would have had six possible inputs, etc. Obviously at some point the number and complexity of decisions required become prohibitive especially when they must be made concurrent with performing a continuous motor task. Research is needed to determine these limits.

4. MATCHING LEARNER CHARACTERISTICS WITH TRAINING ALTERNATIVES

A third approach to individualized motor skill training involves the measurement of learner characteristics that have an effect on learning and the application of these measures to the selection of an appropriate training strategy for each student. Recent work by Pask [19] on cognitive tasks indicates that the matching of the instructional strategy and individual characteristics is a critical factor in maximizing training efficiency. Pask's research points out that when the student's preferred learning style and teaching strategy are mismatched, learning is severely disrupted in terms of comprehension and retention. The question arises as to what individual characteristics to measure and how to measure them.

Recent interest in the relationship between information processing skills and motor skills may have implications for investigating individual differences in motor learning. Marteniuk [20]

suggested that limitations in information processing capabilities can limit motor performance. If these perceptual or cognitive processes can be measured, differences in information processing skills as they relate to motor skills can be studied.

Savage, Williges, and Williges [2]] used the scores from a battery of six information processing and motor skill tests to generate and cross-validate regression equations predicting training time in a two-dimensional pursuit tracking task using either fixed difficulty or adaptive training. Because the coefficients of multiple determination were consistently high, data from the two samples were pooled and new regression equations were generated. Each of these equations was reliable at the .001 level of significance. Although the Embedded Figures Test was the dominant predictor in both equations, all other factors differed. In addition, sex of the student was a reliable predictor only for adaptive training. These differences may discriminate between the two training alternatives so that students can be assigned based on individual information processing characteristics. However, research is necessary to establish the validity of the regression approach to training group assignment. In a current study at the Human Factors Laboratory, Virginia Polytechnic Institute and State University, the regression approach is being evaluated. Three groups of students will be either randomly assigned to a training condition or matched or mismatched to a training condition based on predicted time-to-exit scores from the regression equations. Training time and transfer performance will be measured.

The use of minicomputers or microprocessors for pretesting and calculating predicted scores from the regression equations makes the pairing of learner characteristics and training alternatives feasible. However, additional research is needed to determine the specific dimensions of individual differences that are associated with various training alternatives, the methods for improving the definition and measurement of learner characteristics, and the matching rules that can be used to select the optimal strategy for various characteristic profiles.

Historically training research has sought the training alternative providing the highest average and least variability in order to maximize training effectiveness. However, no one training alternative is optimal for every student. Perhaps a more profitable approach is to seek interactions between individual learner characteristics and training strategies.

5. CONCLUSION

Preliminary research on each of these three approaches--adaptive training, learner-centered training, and matching learner characteristics to training alternatives--indicates that individual differences can be provided for in motor learning through computer augmentation. For each of these approaches the computer plays a different role. In adaptive training the computer measures student performance and, according to the adaptive logic, adjusts task difficulty or complexity. In learner-centered training the computer monitors student input and adjusts task difficulty. To match learner characteristics to training strategies the computer provides a managerial role. Students are pretested by the computer, test scores are used in the regression equations to determine an optimal training condition for the individual, and the new data are used to update the regression models. However, before any of these techniques are ready for use in operational simulation devices, fundamental research is necessary to assure maximum training, transfer, and retention at the lowest cost.

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